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(continued on next page)

(54) Abstract Title: **Battery charger for several nominal voltages**

(57) A battery charger is capable of charging two lithium batteries, suitable for a cordless power tool, having different nominal voltages. The batteries have identification components representing a value of the nominal voltage or a range for the nominal voltage, and the charger reads the identification component and adapts its operation. A microcontroller may be present in the battery or in the charger, and the charger may also read battery condition data during charging.

Also claimed are an electrical device capable of identifying battery chemistry or nominal voltage; a battery having an interrupt condition switch; a battery charger capable of charging two batteries with different chemistries; and a battery charger that selects a threshold according to a nominal voltage of a battery pack.

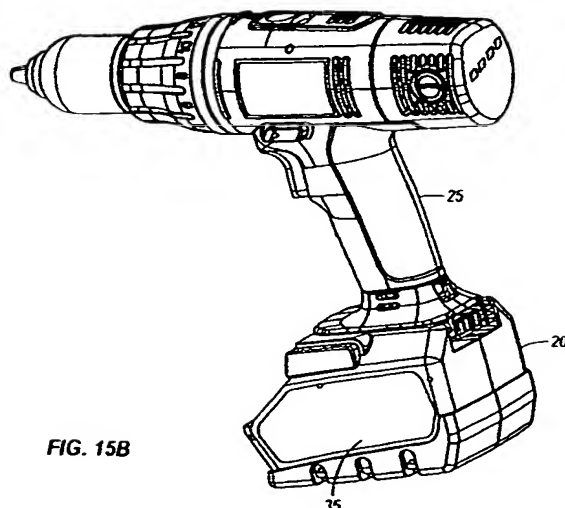


FIG. 15B

**GB 2396755 A continuation**

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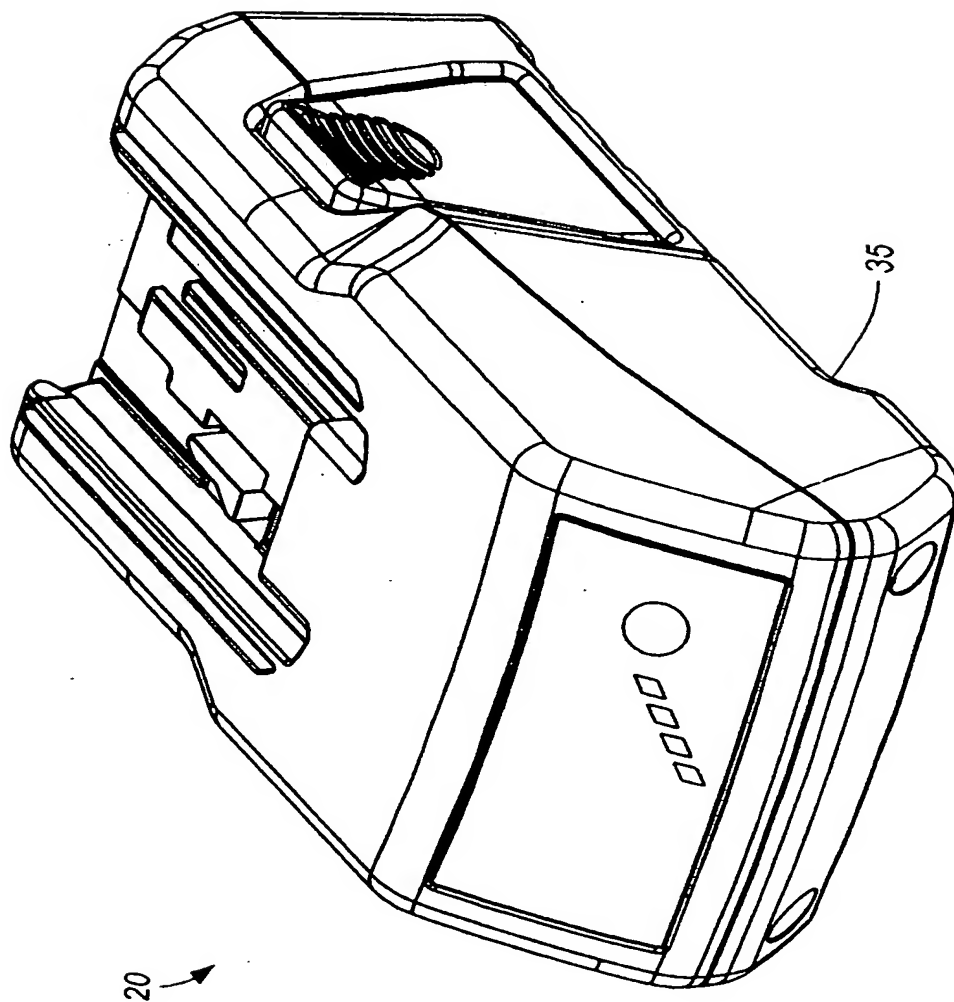


FIG. 1

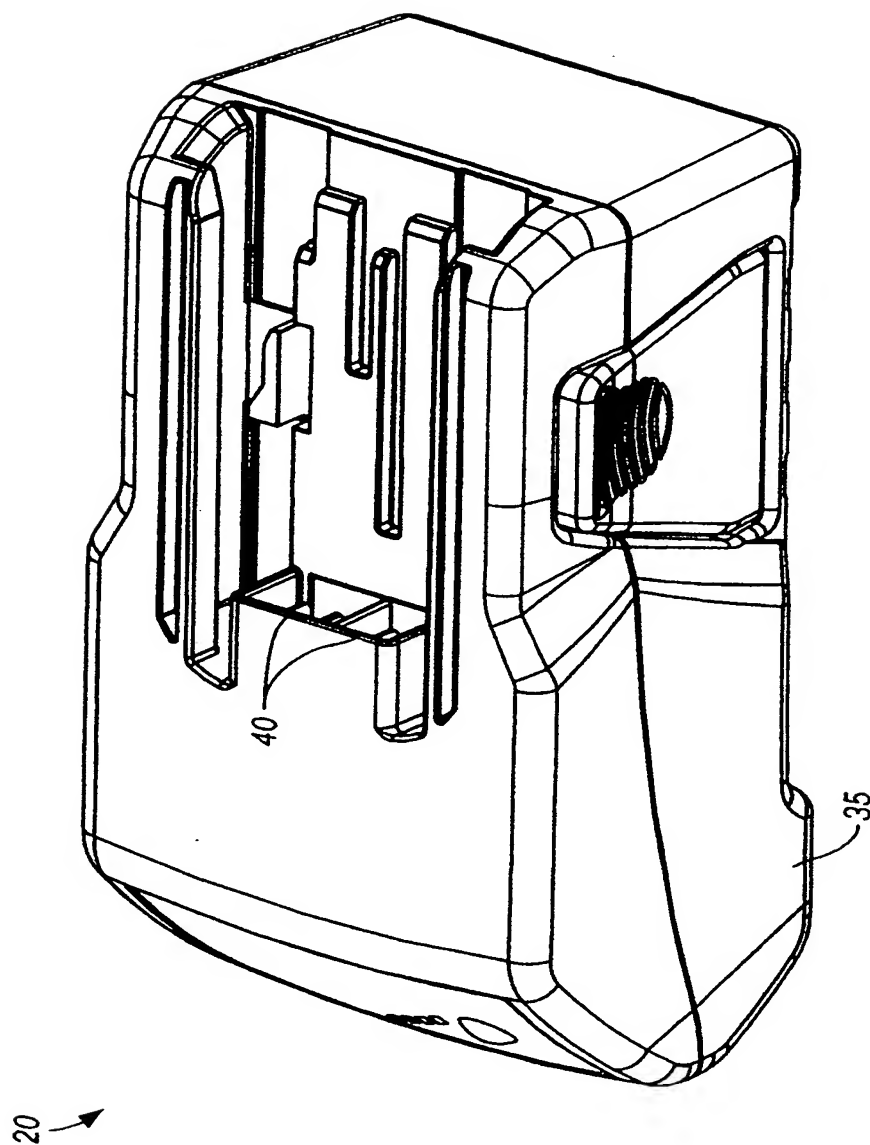
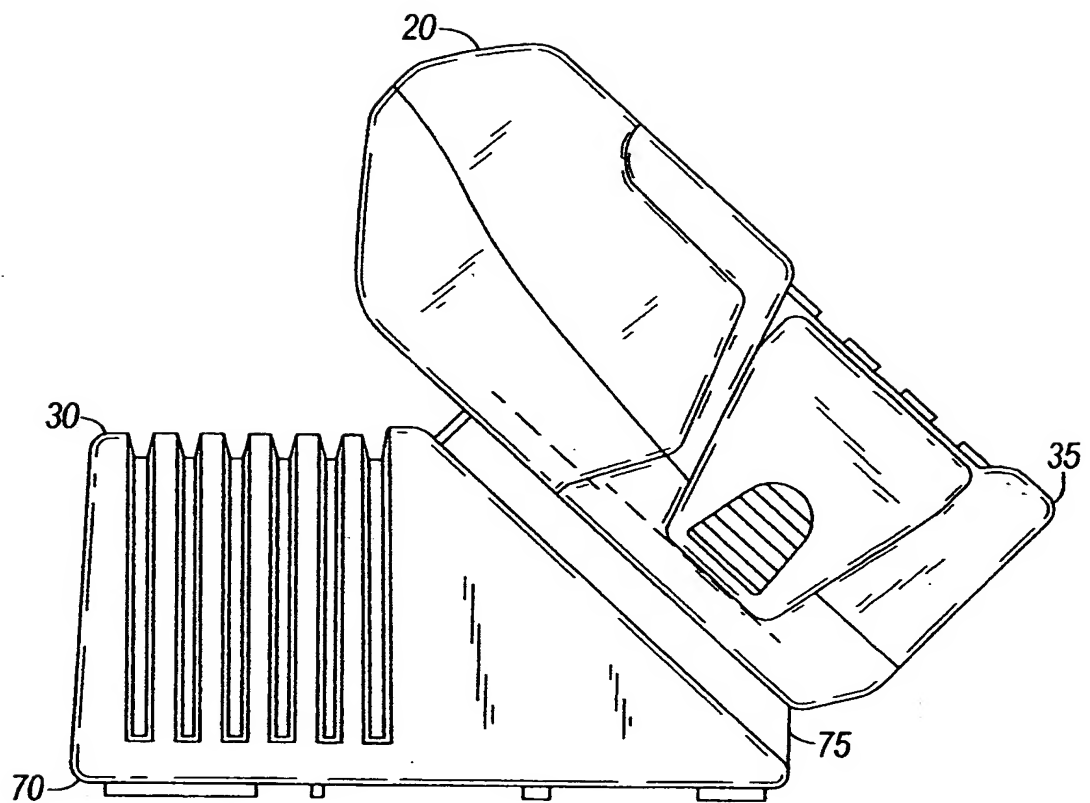


FIG. 2



**FIG. 3**

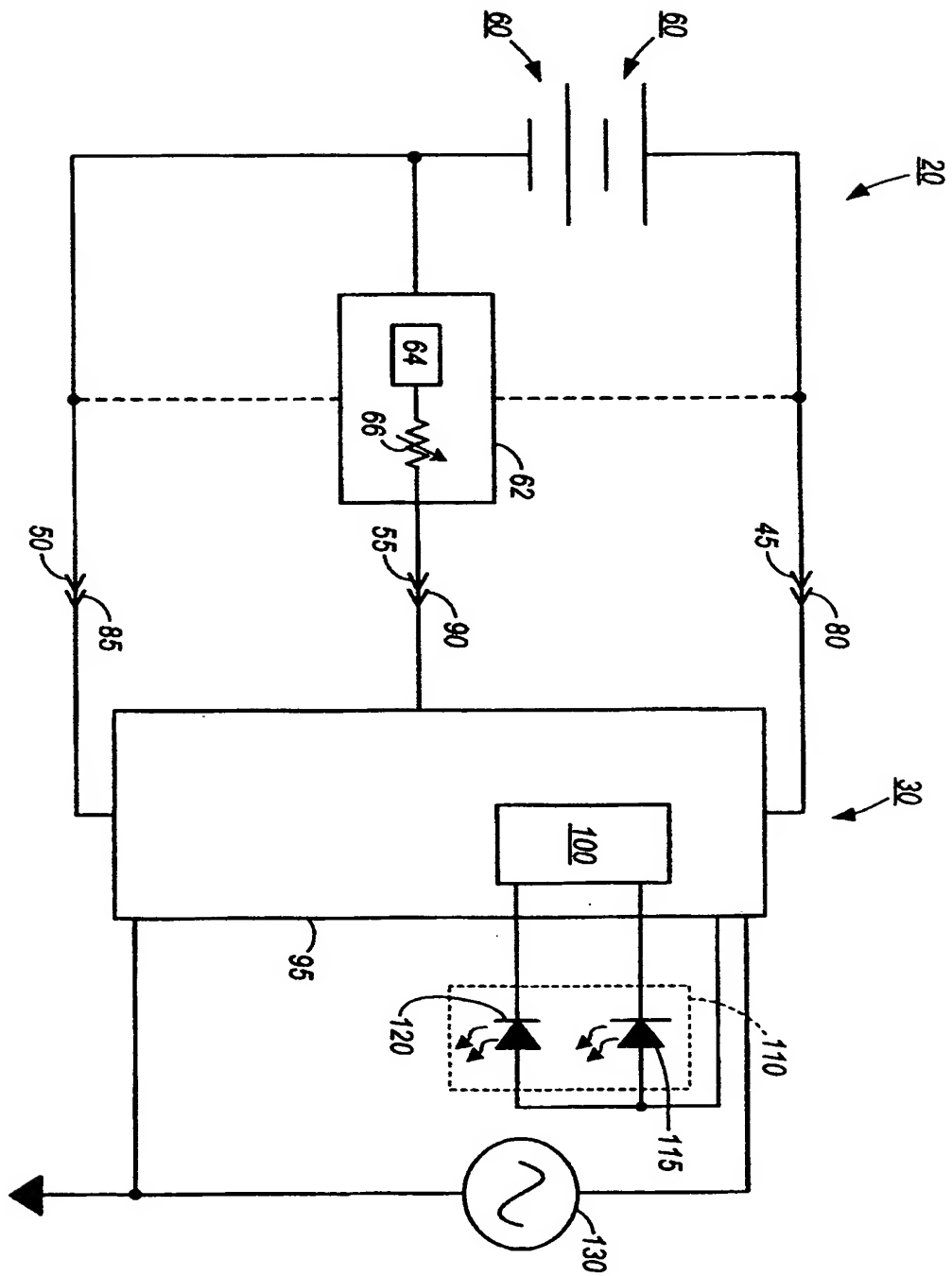
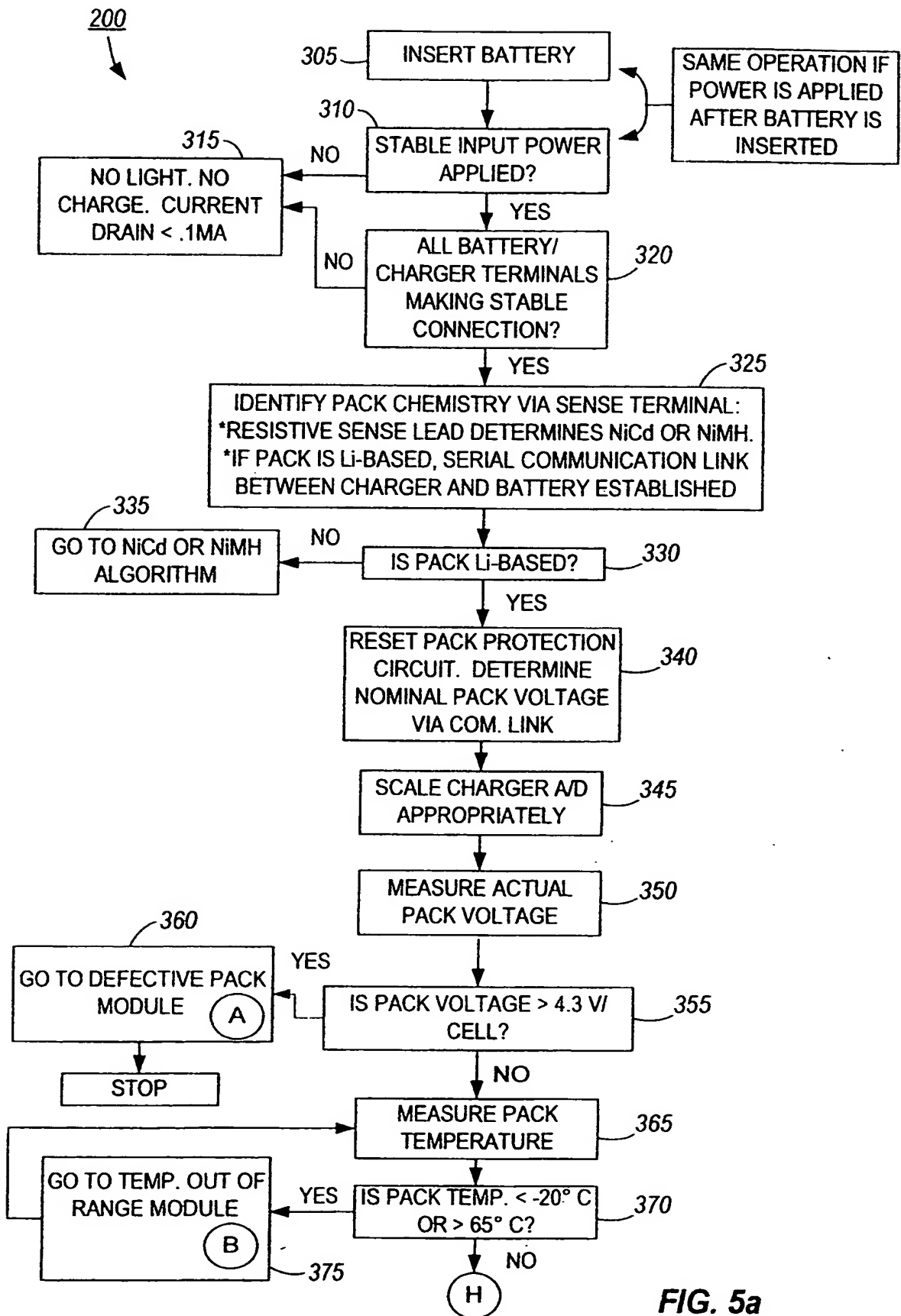


FIG. 4



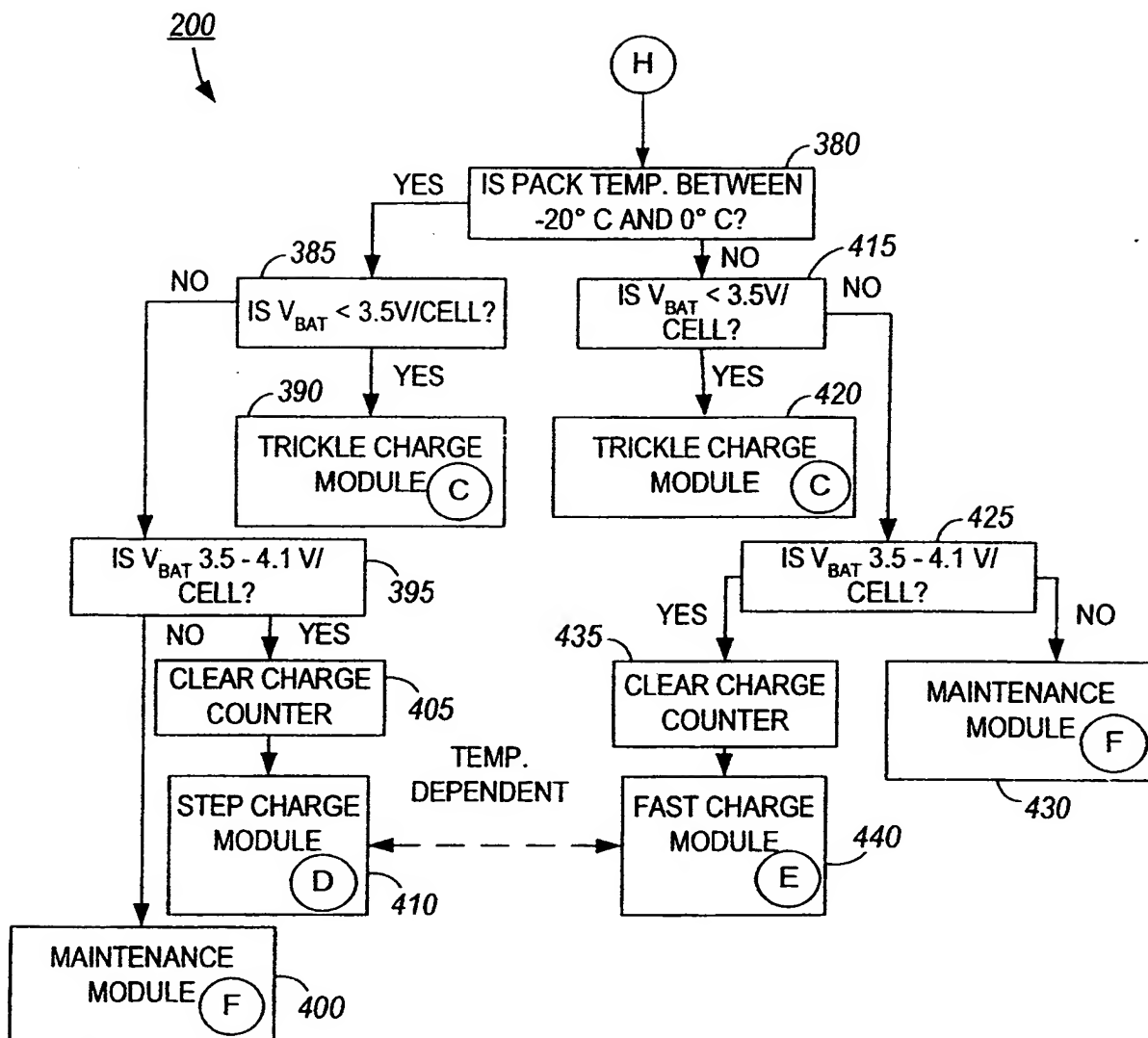
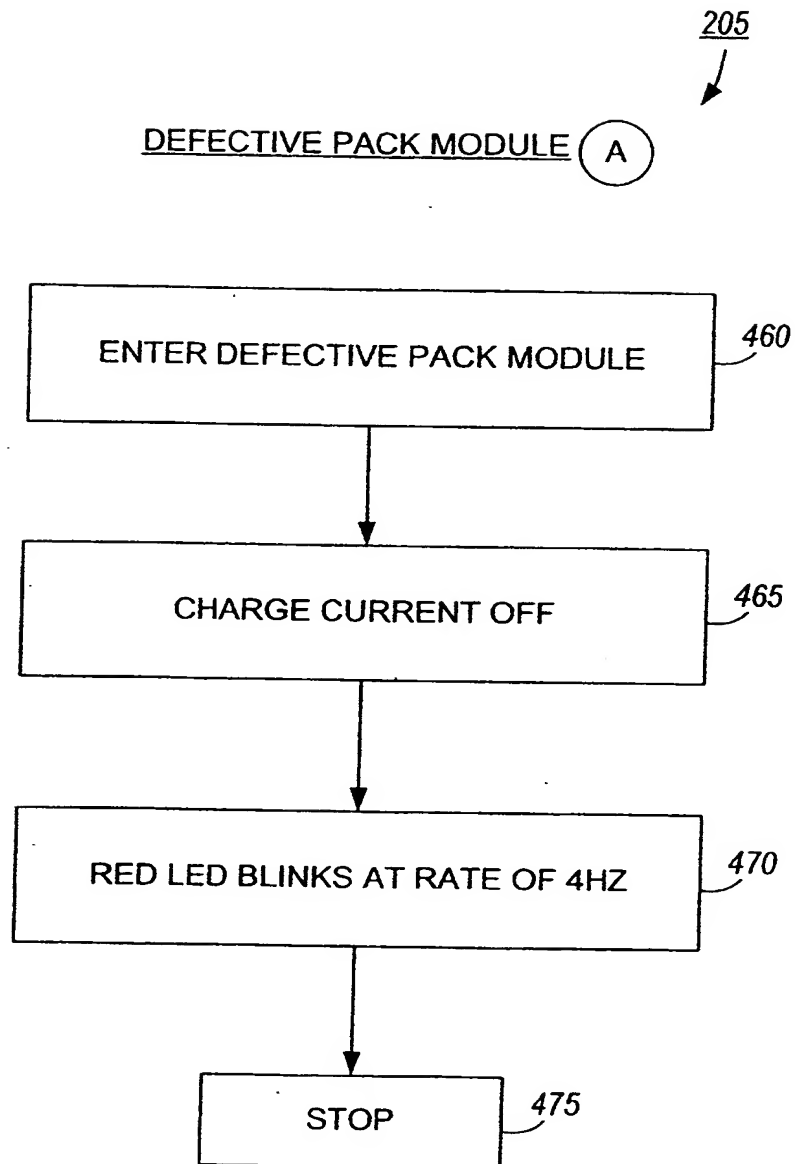


FIG. 5b





**FIG. 6**

210



TEMP. OUT OF RANGE MODULE (B)

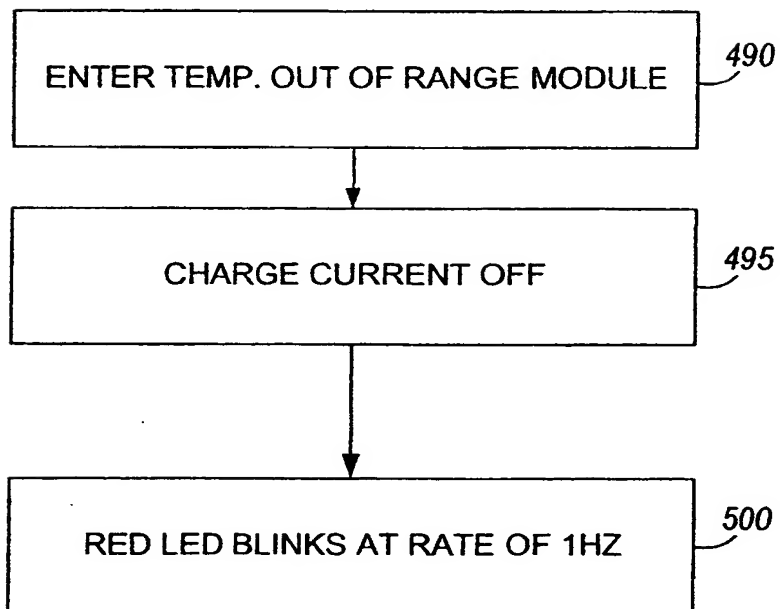
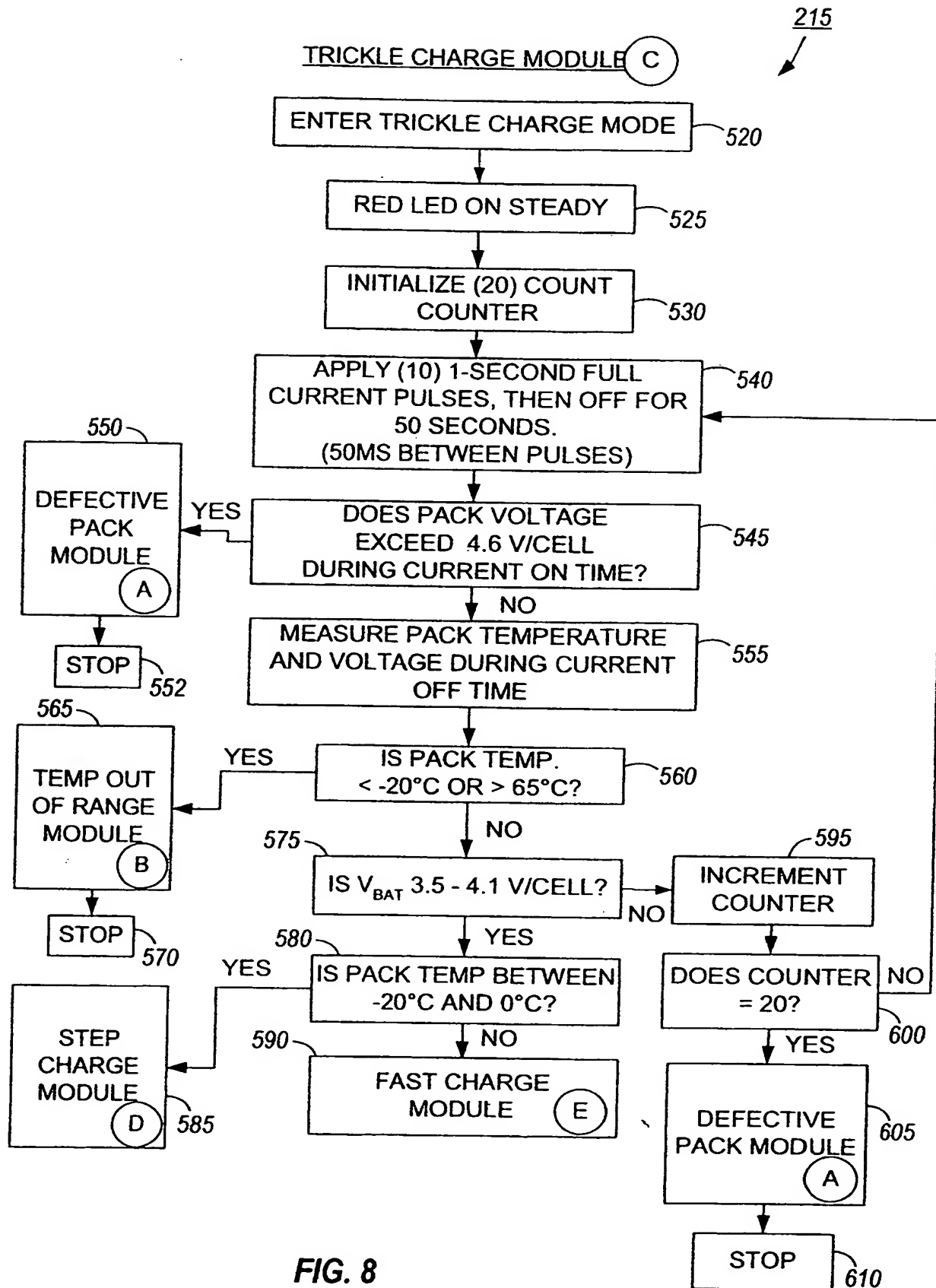
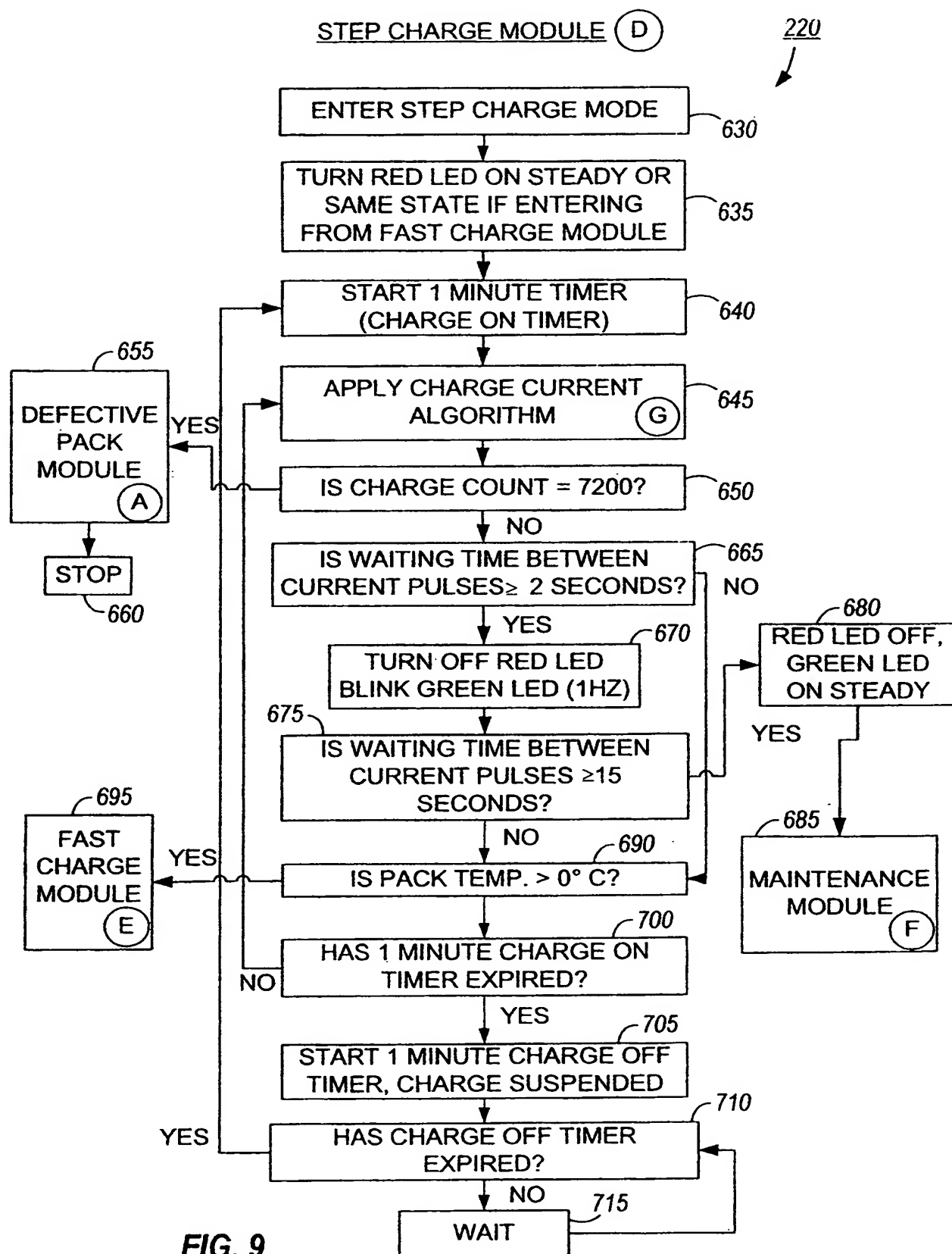
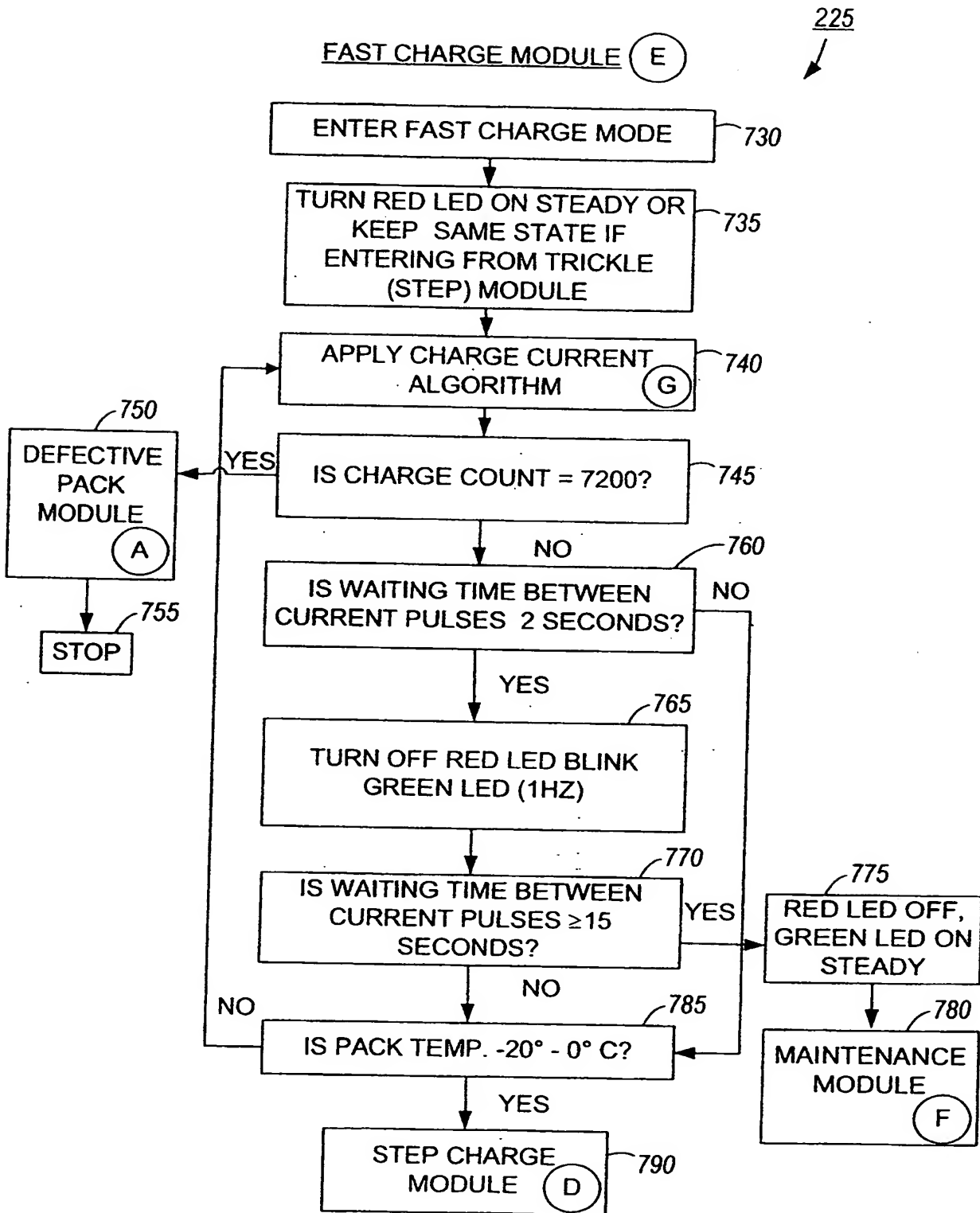


FIG. 7

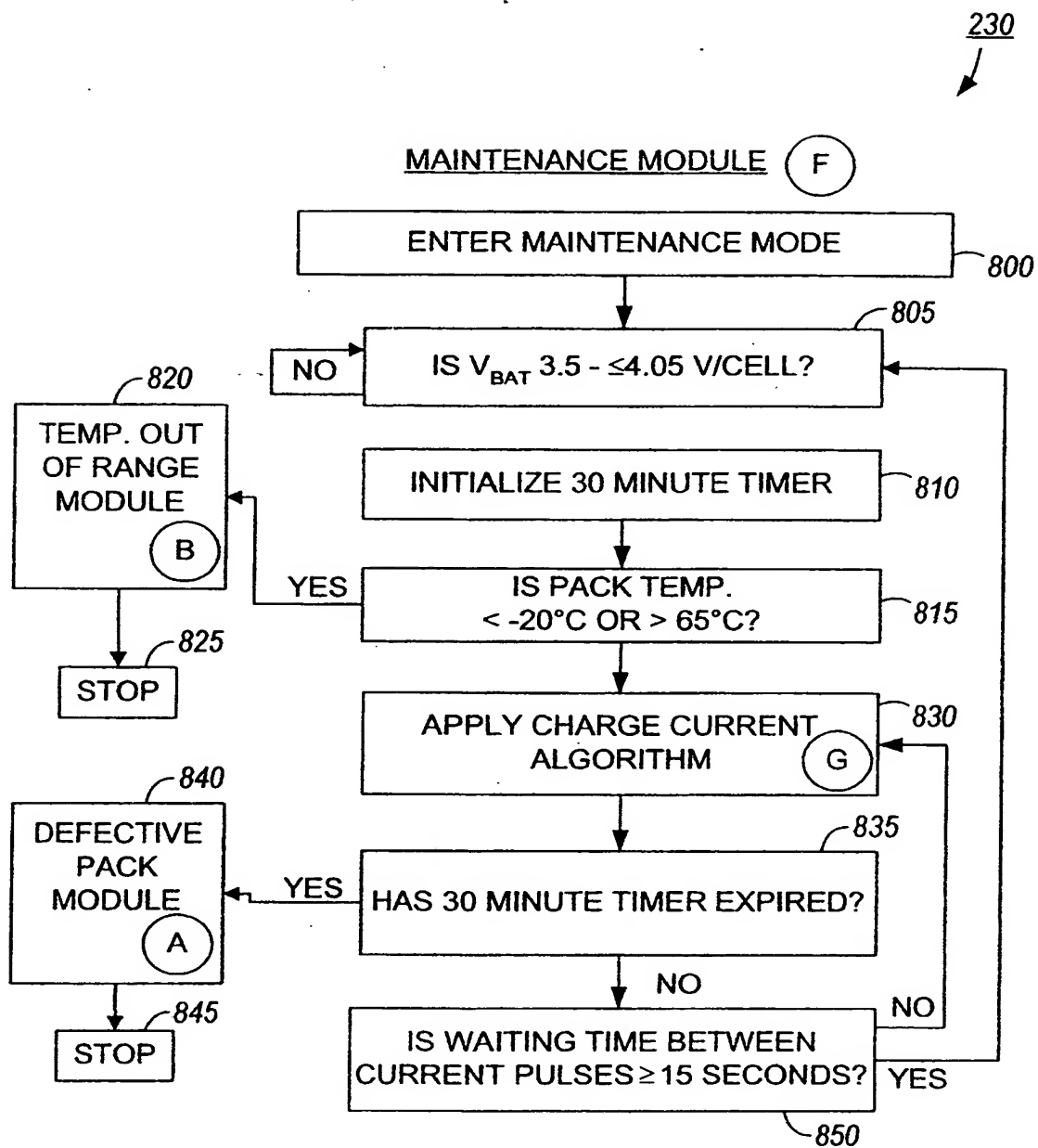




**FIG. 9**



**FIG. 10**



**FIG. 11**

## CHARGE CURRENT ALGORITHM (G)

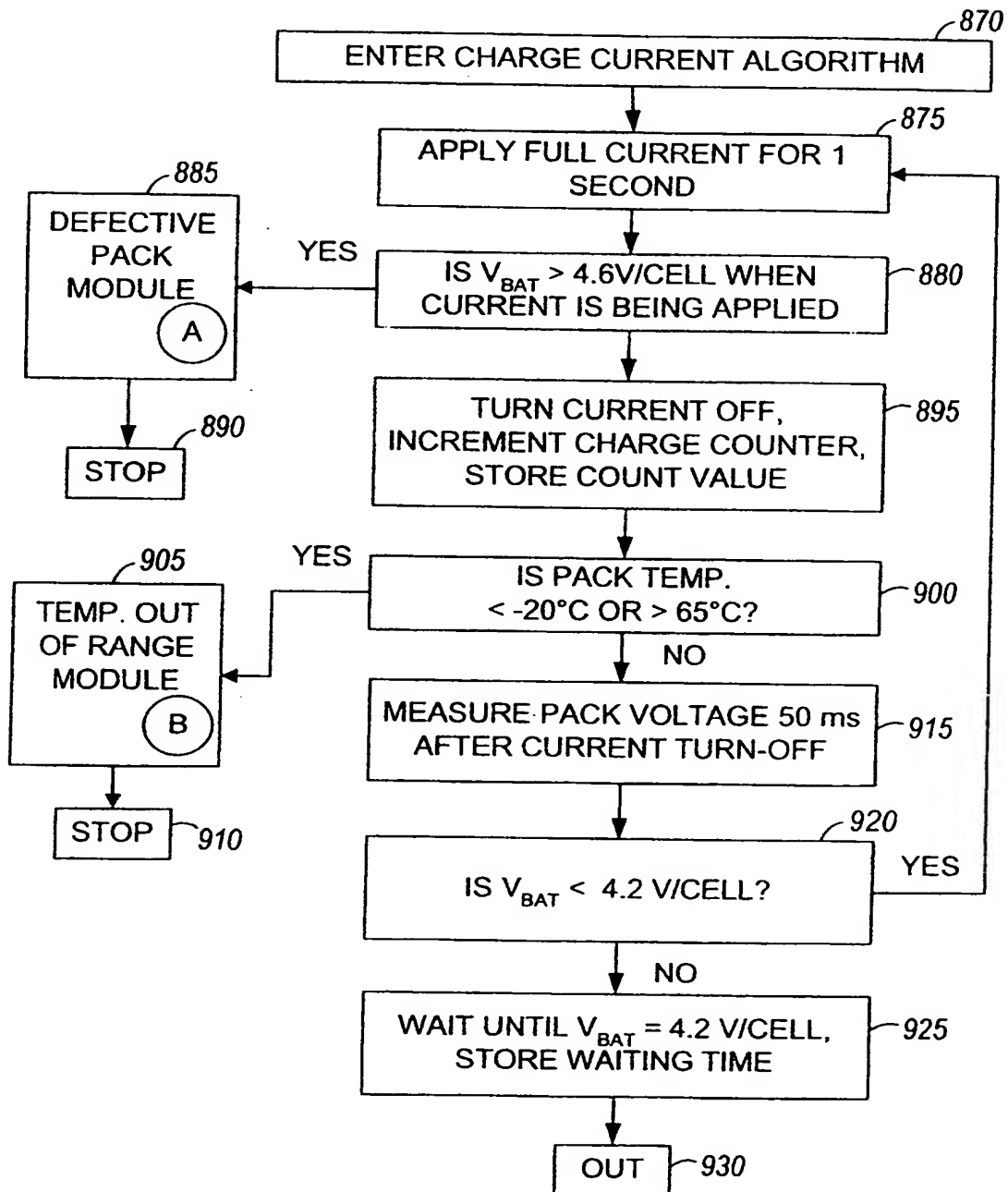
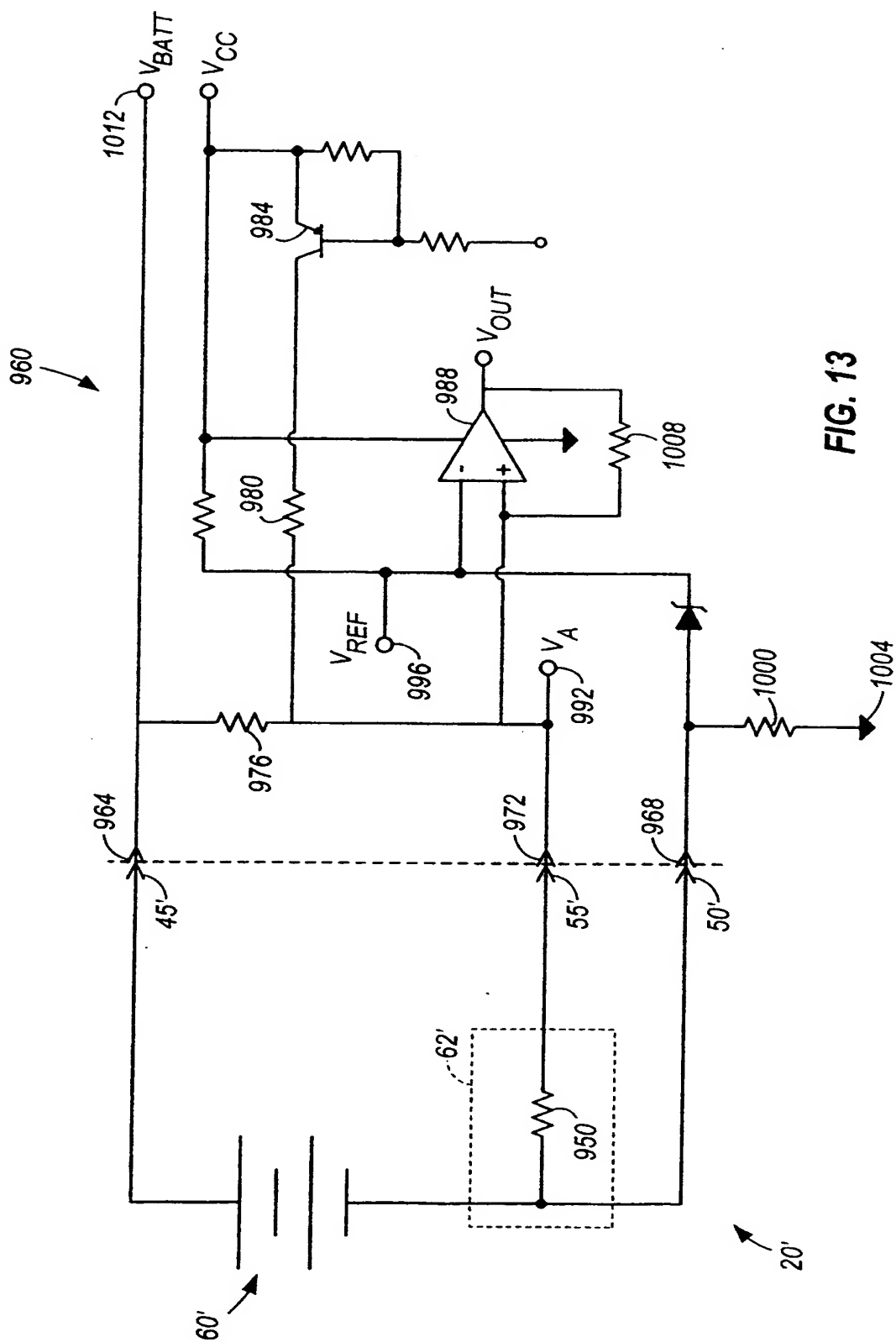


FIG. 12





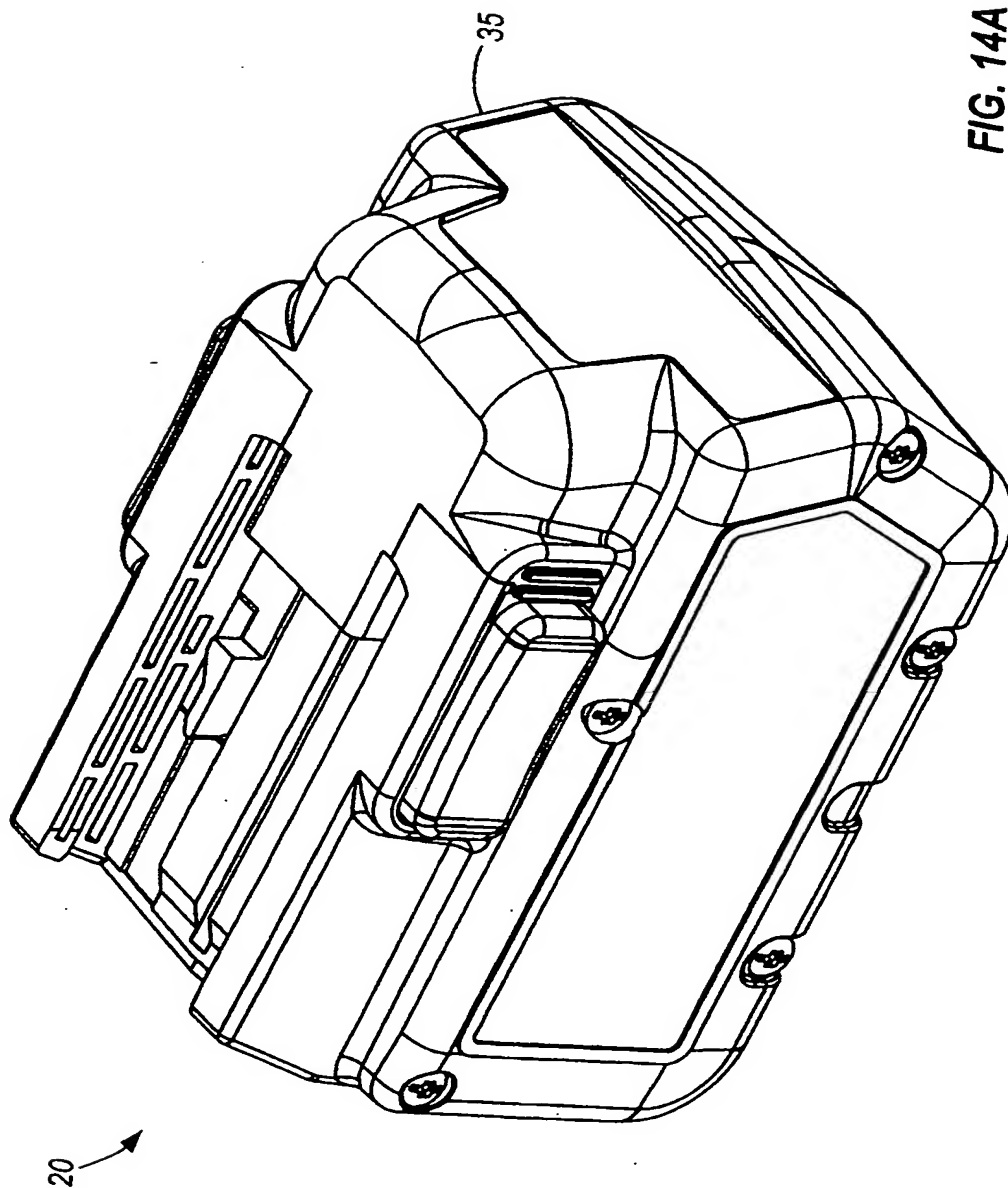


FIG. 14A

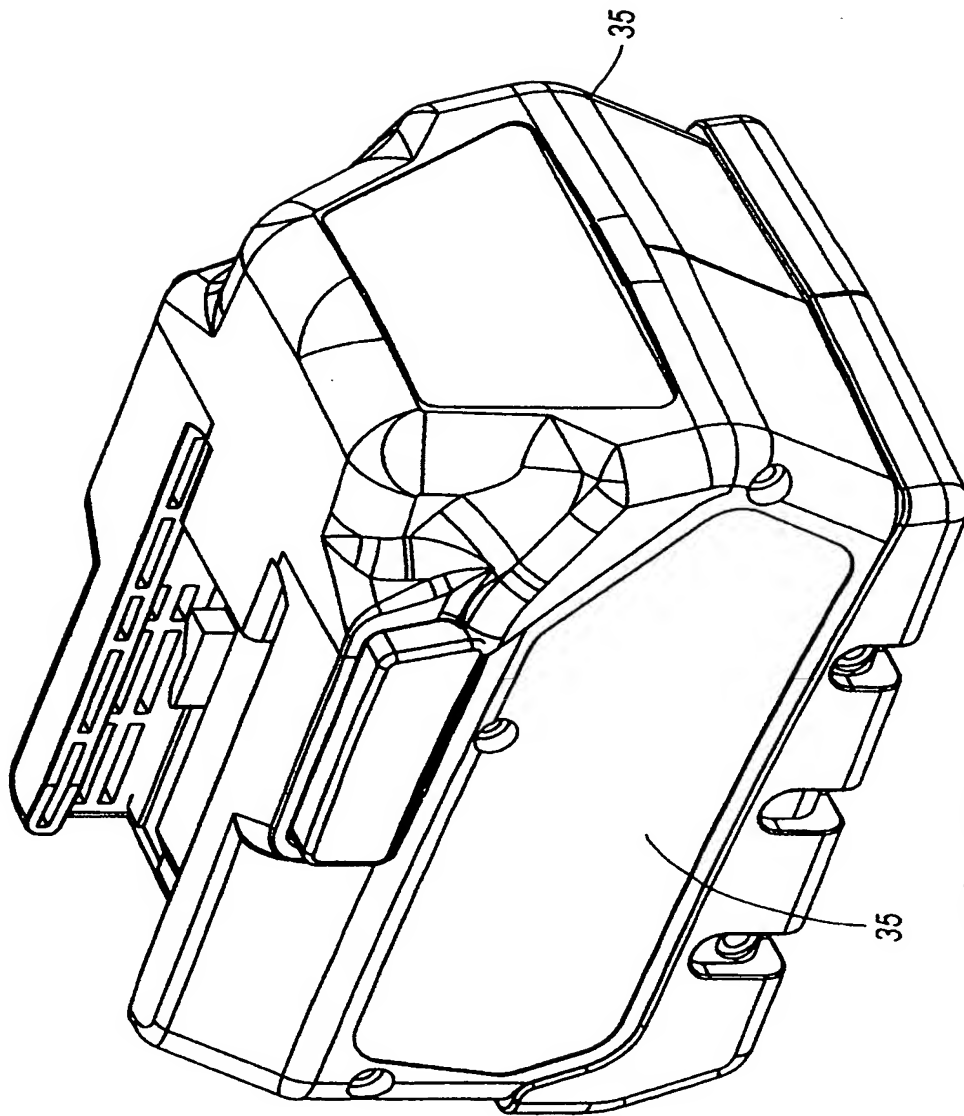


FIG. 14B

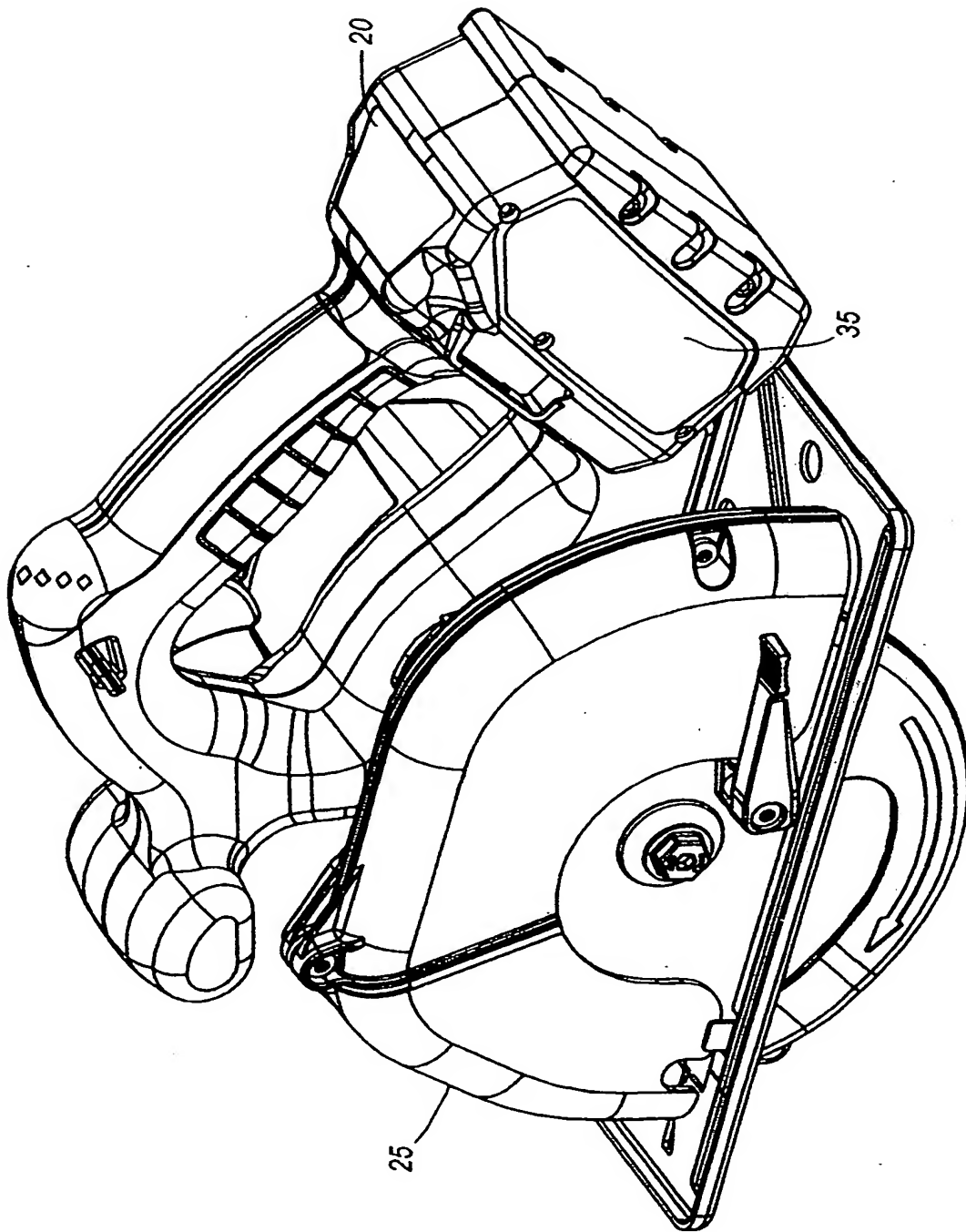


FIG. 15A

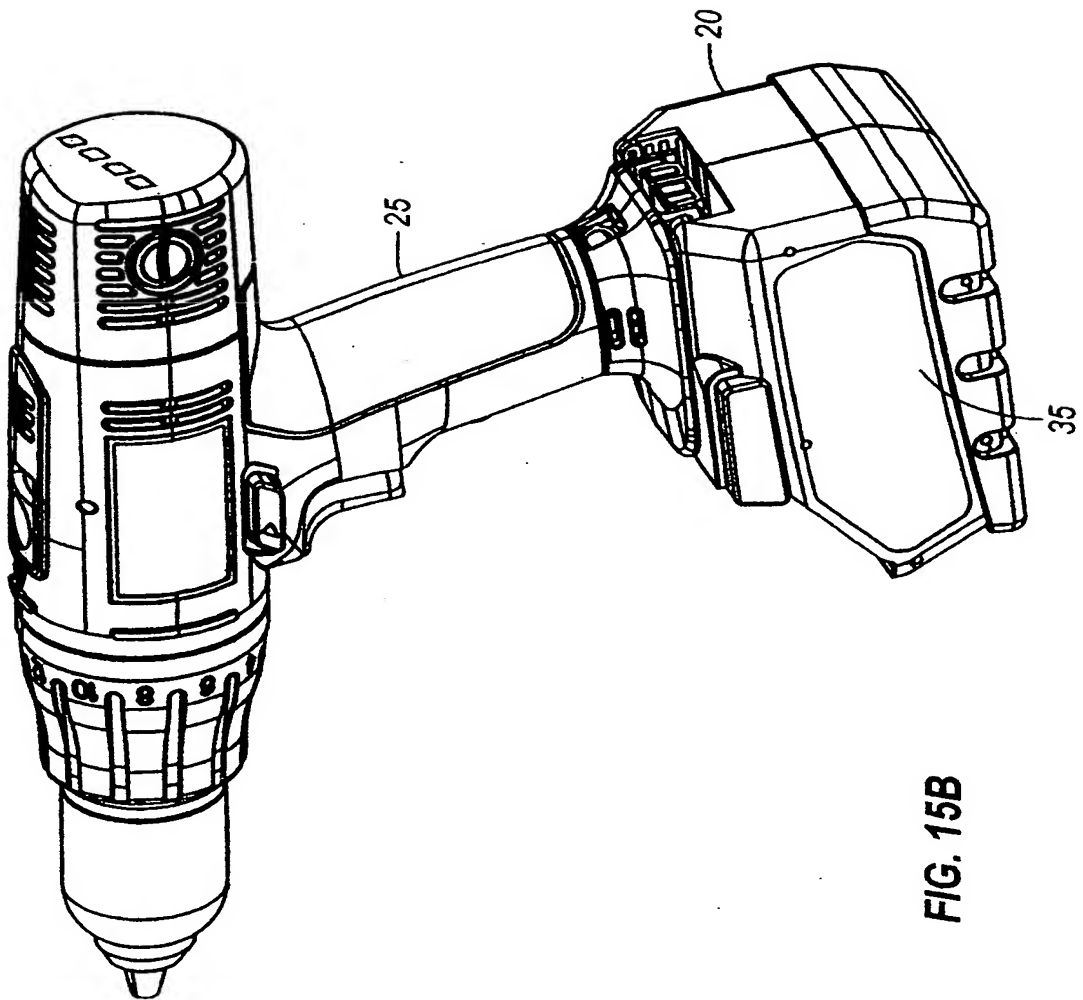


FIG. 15B

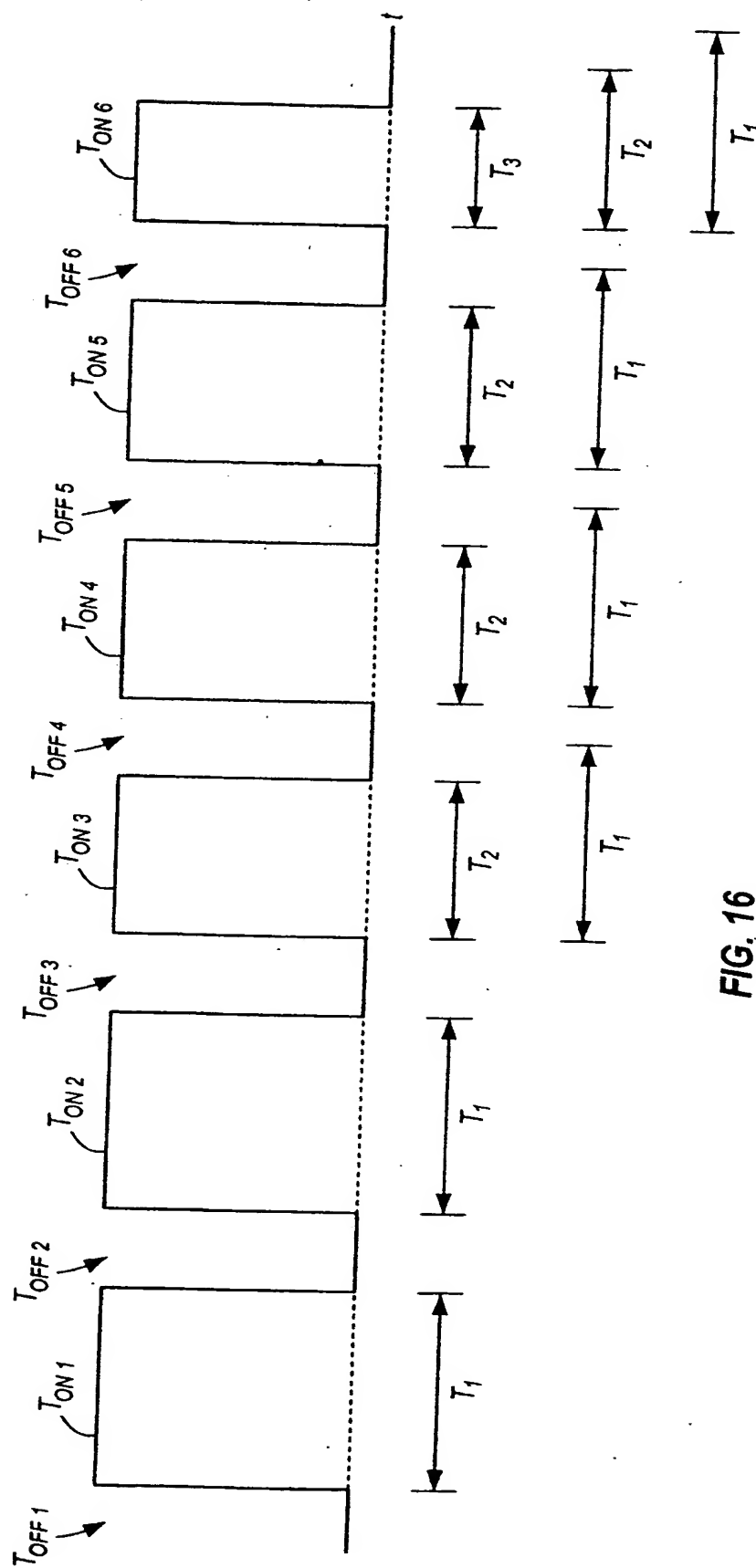
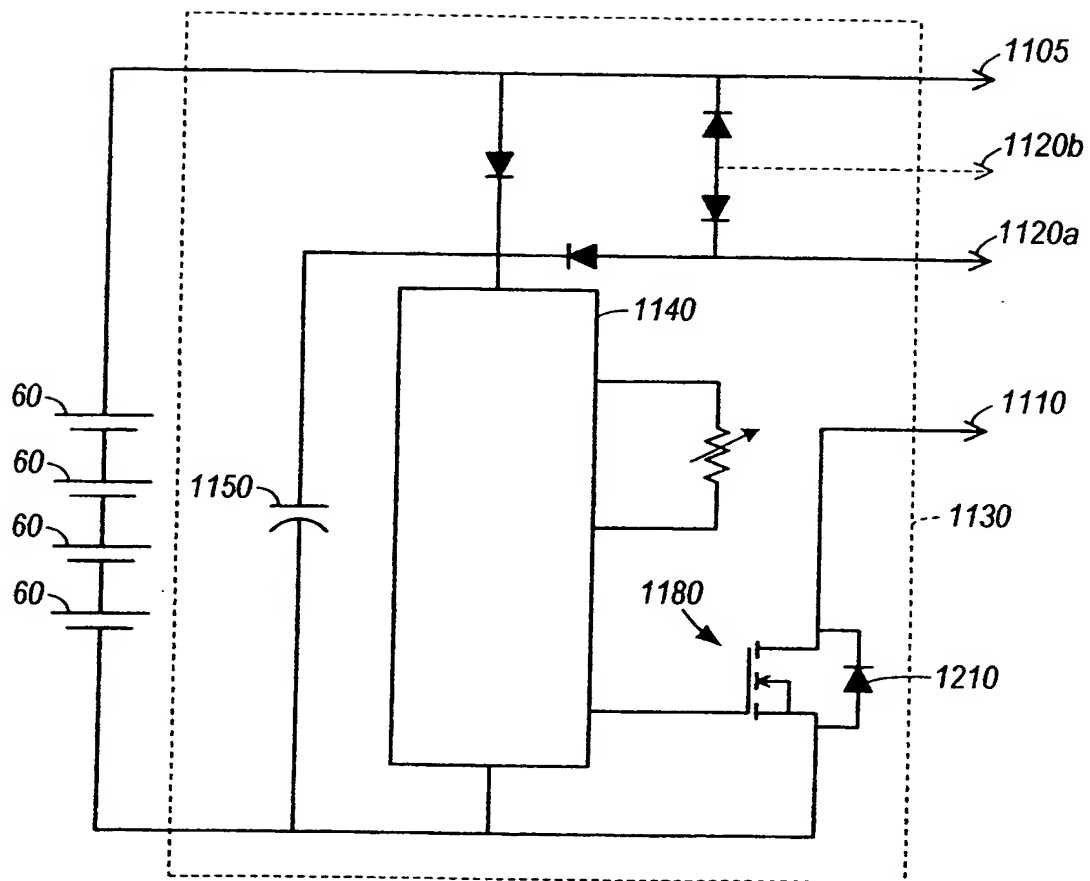


FIG. 16



**FIG. 17**

**METHOD AND SYSTEM FOR BATTERY CHARGING****FIELD OF THE INVENTION**

The present patent application claims the benefit of prior filed co-pending U.S. provisional patent application Serial No. 60/428,358, filed on November 22, 2002; Serial No. 60/428,450, filed on November 22, 2002; Serial No. 60/428,452, filed on November 22, 2002; Serial No. 60/400,692, filed January 17, 2003; Serial No. 60/440,693, filed on January 17, 2003, prior filed co-pending U.S. provisional patent application entitled "METHOD AND SYSTEM FOR BATTERY PROTECTION" filed on November 19, 2003 (Atty. Docket No. 066042-9536-00); and prior filed co-pending U.S. provisional patent application entitled "METHOD AND SYSTEM FOR BATTERY CHARGING" filed on November 19, 2003 (Atty. Docket No. 066042-9538-00), the entire contents of which are hereby incorporated by reference. The entire content of U.S. patent application entitled "METHOD AND SYSTEM FOR BATTERY PROTECTION" filed on November 20, 2003 (Atty. Docket No. 066042-9536-01) is also hereby incorporated by reference.

**FIELD OF THE INVENTION**

The present invention generally relates to a method and system for battery charging and, more particularly, to a method and system for power tool battery charging.

5

**BACKGROUND OF THE INVENTION**

Cordless power tools are typically powered by portable battery packs. These battery packs range in battery chemistry and nominal voltage and can be used to power numerous tools and electrical devices. Typically, the battery chemistry of a power tool battery is either Nickel-Cadmium ("NiCd") or Nickel-Metal Hydride ("NiMH"). The nominal voltage of the battery pack usually ranges from about 2.4 V to about 24 V.

10

**SUMMARY OF THE INVENTION**

Some battery chemistries (such as, for example, Lithium ("Li"), Lithium-ion ("Li-ion") and other Lithium-based chemistries) require precise charging schemes and charging operations with controlled discharge. Insufficient charging schemes and uncontrolled discharging schemes may produce excessive heat build-up, excessive overcharged conditions and/or excessive overdischarged conditions. These conditions and build-ups

15

can cause irreversible damage to the batteries and can severely impact the battery's capacity.

The present invention provides a system and method for charging a battery. In some constructions and in some aspects, the invention provides a battery charger capable of fully charging various battery packs with different battery chemistries. In some constructions and in some aspects, the invention provides a battery charger capable of fully charging lithium-based batteries, such as, for example, lithium-cobalt batteries, lithium-manganese batteries and spinel batteries. In some constructions and in some aspects, the invention provides a battery charger capable of charging Lithium-based chemistry battery packs of different nominal voltages or in different nominal voltage ranges. In some constructions and in some aspects, the inventions provides a battery charger having various charging modules that are implemented based on different battery conditions. In some constructions and in some aspects, the invention provides a method and system for charging a lithium-based battery by applying pulses of constant current. The time between pulses and the length of the pulses may be increased or decreased by the battery charger depending on certain battery characteristics.

Independent features and independent advantages of the invention will become apparent to those skilled in the art upon review of the following detailed description, claims, and drawings.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a perspective view of a battery.

Fig. 2 is another perspective view of a battery, such as the battery shown in Fig. 1.

Fig. 3 is a perspective view of a battery, such as the battery shown in Fig. 1, electrically and physically connected to a battery charger.

Fig. 4 is a schematic view of a battery electrically connected to a battery charger, such as the battery and battery charger shown in Fig. 3.

Figs. 5a and 5b are flowcharts illustrating operation of a battery charger embodying aspects of the invention, such as the battery charger shown in Fig. 3.

Fig. 6 is a flowchart illustrating a first module capable of being implemented on a battery charger embodying aspects of the invention, such as the battery charger shown in Fig. 3.



Fig. 7 is a flowchart illustrating a second module capable of being implemented on a battery charger embodying aspects of the invention, such as the battery charger shown in Fig. 3.

5 Fig. 8 is a flowchart illustrating a third module capable of being implemented on a battery charger embodying aspects of the invention, such as the battery charger shown in Fig. 3.

Fig. 9 is a flowchart illustrating a fourth module capable of being implemented on a battery charger embodying aspects of the invention, such as the battery charger shown in Fig. 3.

10 Fig. 10 is a flowchart illustrating a fifth module capable of being implemented on a battery charger embodying aspects of the invention, such as the battery charger shown in Fig. 3.

Fig. 11 is a flowchart illustrating a sixth module capable of being implemented on a battery charger embodying aspects of the invention, such as the battery charger shown in Fig. 3.

15 Fig. 12 is a flowchart illustrating a charging algorithm capable of being implemented on a battery charger embodying aspects of the invention, such as the battery charger shown in Fig. 3.

Fig. 13 is a schematic diagram of a battery electrically connected to a battery charger.

Fig. 14A-B are views of other constructions of a battery.

Fig. 15A-B are perspective views of a battery, such as one of the batteries shown in Figs. 1, 2, and 14A-B, electrically and physically connected to a power tool.

Fig. 16 is a schematic view of the charging current for a battery.

25 Fig. 17 is another schematic diagram of a battery.

Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being  
30 practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations

thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

### **DETAILED DESCRIPTION OF THE DRAWINGS**

A battery pack or battery 20 is illustrated in Figs. 1 and 2. The battery 20 is  
5 configured for transferring power to and receiving power from one or more electrical  
devices, such as, for example, a power tool 25 (shown in Figs. 15A-B) and/or a battery  
charger 30 (shown in Figs. 3 and 4). In some constructions and in some aspects, the  
battery 20 can have any battery chemistry such as, for example, lead-acid, Nickel-  
cadmium ("NiCd"), Nickel-Metal Hydride ("NiMH"), Lithium ("Li"), Lithium-ion ("L-  
10 ion"), another Lithium-based chemistry or another rechargeable battery chemistry. In  
some constructions and in some aspects, the battery 20 can supply a high discharge current  
to electrical devices, such as, for example, a power tool, having high-current discharge  
rates. In the illustrated constructions, the battery 20 has a battery chemistry of Li, Li-ion  
or another Li-based chemistry and supplies an average discharge current that is equal to or  
15 greater than approximately 20 A. For example, in the illustrated construction, the battery  
20 can have a chemistry of lithium-cobalt ("Li-Co"), lithium-manganese ("Li-Mn") spinel,  
or Li-Mn Nickel.

In some constructions and in some aspects, the battery 20 can also have any  
nominal voltage such as, for example, a nominal voltage ranging from approximately 9.6  
20 V to approximately 50 V. In one construction (see Figs. 1-3), for example, the battery 20  
has a nominal voltage of approximately 21 V. In another construction (see Fig. 14), the  
battery 20A has a nominal voltage of approximately 28 V. It should be understood that, in  
other constructions, the battery 20 may have another nominal voltage in another nominal  
voltage range.

25 The battery 20 includes a housing 35 which provides terminal supports 40. The  
battery 20 further includes one or more battery terminals supported by the terminal  
supports 40 and connectable to an electrical device, such as the power tool 25 and/or the  
battery charger 30. In some constructions, such as, for example, the construction  
illustrated in Fig. 4, the battery 20 includes a positive battery terminal 45, a negative  
30 battery terminal 50 and a sense battery terminal 55. In some constructions, the battery 20  
includes more or fewer terminals than in the construction shown.

The battery 20 includes one or more battery cells 60 each having a chemistry and a  
nominal voltage. In some constructions, the battery 20 has a battery chemistry of Li-ion, a

nominal voltage of approximately 18 V or 21 V and includes five battery cells. In some constructions, each battery cell 60 has a chemistry of Li-ion, and each battery cell 60 has substantially the same nominal voltage, such as, for example, approximately 3.6 V or approximately 4.2 V.

5 In some constructions and in some aspects, the battery 20 includes an identification circuit or component electrically connected to one or more battery terminals. In some constructions, an electrical device, such as, for example, a battery charger 30 (shown in Figs. 3 and 4) would "read" the identification circuit or component or receive an input based on the identification circuit or component in order to determine one or more battery  
10 characteristics. In some constructions, the battery characteristics could include, for example, the nominal voltage of the battery 20, the temperature of the battery 20 and/or the chemistry of the battery 20.

In some constructions and in some aspects, the battery 20 includes a control device, a microcontroller, a microprocessor or a controller electrically connected to one or more  
15 battery terminals. The controller communicates with the electrical devices, such as a battery charger 30, and provides information to the devices regarding one or more battery characteristics or conditions, such as, for example, the nominal voltage of the battery 20, individual cell voltages, the temperature of the battery 20 and/or the chemistry of the battery 20. In some constructions, such as, for example, the construction illustrated in Fig.  
20 4, the battery 20 includes an identification circuit 62 having a microprocessor or controller 64.

In some constructions and in some aspects, the battery 20 includes a temperature-sensing device or thermistor. The thermistor is configured and positioned within the battery 20 to sense a temperature of one or more battery cells or a temperature of the  
25 battery 20 as a whole. In some constructions, such as, for example, the construction illustrated in Fig. 4, the battery 20 includes a thermistor 66. In the illustrated construction, the thermistor 66 is included in the identification circuit 62.

As shown in Figs. 3 and 4, the battery 20 is also configured to connect with an electrical device, such as a battery charger 30. In some constructions, the battery charger  
30 30 includes a housing 70. The housing 70 provides a connection portion 75 to which the battery 20 is connected. The connecting portion 75 includes one or more electrical device terminals to electrically connect the battery 20 to the battery charger 30. The terminals included in the battery charger 30 are configured to mate with the terminals included in the battery 20 and to transfer and receive power and information from the battery 20.

In some constructions, such as, for example, the construction illustrated in Fig. 4, the battery charger 30 includes a positive terminal 80, a negative terminal 85 and a sense terminal 90. In some constructions, the positive terminal 80 of the battery charger 30 is configured to mate with the positive battery terminal 45. In some constructions, the  
5 negative terminal 85 and the sense terminal 90 of the battery charger 30 are configured to mate with the negative battery terminal 50 and the sense battery terminal 55, respectively.

In some constructions and in some aspects, the battery charger 30 also includes charging circuitry 95. In some constructions, the charging circuitry 95 includes a control device, a microcontroller, a microprocessor or a controller 100. The controller 100  
10 controls the transfer of power between the battery 20 and the battery charger 30. In some constructions, the controller 100 controls the transfer of information between the battery 20 and the battery charger 30. In some constructions, the controller 100 identifies and/or determines one or more characteristics or conditions of the battery 20 based on signals received from the battery 20. Also, the controller 100 can control operation of the charger  
15 30 based on identification characteristics of the battery 20.

In some constructions and in some aspects, the controller 100 includes various timers, back-up timers and counters and/or can perform various timing and counting functions. The timers, back-up timers and counters are used and controlled by the controller 100 during various charging steps and/or modules. The timers, back-up timers  
20 and counters will be discussed below.

In some constructions and in some aspects, the battery charger 30 includes a display or indicator 110. The indicator 110 informs a user of the status of the battery charger 30. In some constructions, the indicator 110 can inform the user of different stages of charging, charging modes or charging modules that are beginning and/or being  
25 completed during operation. In some constructions, the indicator 110 includes a first light-emitting diode ("LED") 115 and a second LED 120. In the illustrated construction, the first and second LEDs 115 and 120 are different colored LEDs. For example, the first LED 115 is a red LED, and the second LED 120 is a green LED. In some constructions, the controller 100 activates and controls the indicator 110. In some constructions, the  
30 indicator 110 is positioned on the housing 70 or included in the housing 70 such that the indicator 110 is visible to the user. Display could also include an indicator showing percent charged, time remaining, etc. In some constructions, the display or indicator 110 may include the fuel gauge provided on the battery 20.

The battery charger 30 is adapted to receive an input of power from a power source 130. In some constructions, the power source 130 is approximately a 120-V AC, 60-Hz signal. In other constructions, the power source 130 is, for example, a constant current source.

5 In some constructions and in some aspects, the battery charger 30 can charge various rechargeable batteries having different battery chemistry and different nominal voltages, as described below. For example, in an exemplary implementation, the battery charger 30 can charge a first battery having a battery chemistry of NiCd and a nominal voltage of approximately 14.4 V, a second battery having a battery chemistry of Li-ion and  
10 a nominal voltage of approximately 18 V, and a third battery having a battery chemistry of Li-ion and a nominal voltage of approximately 28 V. In another exemplary implementation, the battery charger 30 can charge a first Li-ion battery having a nominal voltage of approximately 21 V and a second Li-ion battery having a nominal voltage of approximately 28 V. In this exemplary implementation, the battery charger 30 can  
15 identify the nominal voltages of each battery 20, and either scale certain thresholds accordingly, as discussed below, or modify voltage readings or measurements (taken during charging) according to the battery nominal voltage.

In some constructions, the battery charger 30 can identify the nominal voltage of a battery 20 by “reading” an identification component included in the battery 20 or by  
20 receiving a signal from, for example, a battery microprocessor or controller. In some constructions, the battery charger 30 may include a range of acceptable nominal voltages for various batteries 20 that the charger 30 is able to identify. In some constructions, the range of acceptable nominal voltages can include a range from approximately 8 V to approximately 50 V. In other constructions, the range of acceptable nominal voltages can  
25 include a range from approximately 12 V to approximately 28 V. In further constructions, the battery charger 30 can identify nominal voltages equaling about 12 V and greater. Also in further constructions, the battery charger 30 can identify nominal voltages equaling about 30 V and lower.

In other constructions, the battery charger 30 can identify a range of values that  
30 includes the nominal voltage of the battery 20. For example, rather than identifying that a first battery 20 has a nominal voltage of approximately 18 V, the battery charger 30 can identify that the nominal voltage of the first battery 20 falls within the range of, for example, approximately 18 V to approximately 22 V, or approximately 16 V to approximately 24 V. In further constructions, the battery charger 30 can also identify

other battery characteristics, such as, for example, the number of battery cells, the battery chemistry, and the like.

In other constructions, the charger 30 can identify any nominal voltage of the battery 20. In these constructions, the charge 30 can be capable of charging any nominal voltage battery 20 by adjusting or scaling certain thresholds according to the nominal voltage of the battery 20. Also in these constructions, each battery 20, regardless of the nominal voltage, may receive approximately the same amplitude of charge current for approximately the same amount of time (for example, if each battery 20 is approximately fully discharged). The battery charger 30 can either adjust or scale the thresholds (discussed below) or adjust or scale the measurements according to the nominal voltage of the battery 30 being charged.

For example, the battery charger 30 may identify a first battery having a nominal voltage of approximately 21 V and 5 battery cells. Throughout charging, the battery charger 30 modifies every measurement that the charger 30 samples (e.g., battery voltage) to obtain a per-cell measurement. That is, the charger 30 divides every battery voltage measurement by 5 (e.g., five cells) to obtain, approximately, the average voltage of a cell. Accordingly, all of the thresholds included in the battery charger 30 may correlate to a per-cell measurement. Also, the battery charger 30 may identify a second battery having a nominal voltage of approximately 28 V and 7 battery cells. Similar to the operation with the first battery, the battery charger 30 modifies every voltage measurement to obtain a per-cell measurement. Again, all of the thresholds included in the battery charger 30 may correlate to a per-cell measurement. In this example, the battery charger 30 can use the same thresholds for monitoring and disabling charging for the first and second batteries, enabling the battery charger 30 to charge many batteries over a range of nominal voltages.

In some constructions and in some aspects, the battery charger 30 bases the charging scheme or method for charging the battery 20 on the temperature of the battery 20. In one construction, the battery charger 30 supplies a charging current to the battery 20 while periodically detecting or monitoring the temperature of the battery 20. If the battery 20 does not include a microprocessor or controller, the battery charger 30 periodically measures the resistance of the thermistor 66 after predefined periods of time. If the battery 20 includes a microprocessor or controller, such as controller 64, then the battery charger 30 either: 1) interrogates the controller 64 periodically to determine the battery temperature and/or if the battery temperature is outside an appropriate operating

range(s); or 2) waits to receive a signal from the controller 64 indicating that the battery temperature is not within an appropriate operating range, as will be discussed below.

5 In some constructions and in some aspects, the battery charger 30 bases the charging scheme or method for charging the battery 20 on the present voltage of the battery 20. In some constructions, the battery charger 30 supplies a charging current to the battery 20 while periodically detecting or monitoring the battery voltage after predefined periods of time when the current is being supplied to the battery 20 and/or when the current is not being supplied, as will be discussed below. In some constructions, the battery charger 30 bases the charging scheme or method for charging the battery 20 on  
10 both the temperature and the voltage of the battery 20. Also, charging scheme can be based on individual cell voltages.

Once the battery temperature and/or battery voltage exceeds a predefined threshold or does not fall within an appropriate operating range, the battery charger 30 interrupts the charging current. The battery charger 30 continues to periodically detect or monitor the  
15 battery temperature/voltages or waits to receive a signal from the controller 64 indicating that the battery temperature/voltages are within an appropriate operating range. When the battery temperature/voltages are within an appropriate operating range, the battery charger 30 may resume the charging current supplied to the battery 20. The battery charger 30 continues to monitor the battery temperature/voltages and continues to interrupt and  
20 resume the charging current based on the detected battery temperature/voltages. In some constructions, the battery charger 30 terminates charging after a predefined time period or when the battery capacity reaches a predefined threshold. In other constructions, charging is terminated when the battery 20 is removed from the battery charger 30.

In some constructions and in some aspects, the battery charger 30 includes a  
25 method of operation for charging various batteries, such as the battery 20, having different chemistries and/or nominal voltages. An example of this charging operation 200 is illustrated in Figs. 5a and 5b. In some constructions and in some aspects, the battery charger 30 includes a method of operation for charging Li-based batteries, such as batteries having a Li-Co chemistry, a Li-Mn spinel chemistry, a Li-Mn Nickel chemistry,  
30 and the like. In some constructions and in some aspects, the charging operation 200 includes various modules for performing different functions in response to different battery conditions and/or battery characteristics.

In some constructions and in some aspects, the method of operation 200 includes modules for interrupting charging based on abnormal and/or normal battery conditions. In

some constructions, the charging operation 200 includes a defective pack module, such as the defective pack module illustrated in flowchart 205 of Fig. 6, and/or a temperature out-of-range module, such as the temperature out-of-range module illustrated in flowchart 210 of Fig. 7. In some constructions, the battery charger 30 enters the defective pack module 205 in order to terminate charging based on abnormal battery voltage, abnormal cell voltage and/or abnormal battery capacity. In some constructions, the battery charger 30 enters the temperature out-of-range module 210 in order to terminate charging based on abnormal battery temperature and/or one or more abnormal battery cell temperatures. In some constructions, the charging operation 200 includes more or fewer modules which terminate charging based on more or fewer battery conditions than the modules and conditions discussed above and below.

In some constructions and in some aspects, the charging operation 200 includes various modes or modules for charging the battery 20 based on various battery conditions. In some constructions, the charging operation 200 includes a trickle charge module, such as the trickle charge module illustrated in flowchart 215 of Fig. 8, a step charge module, such as the step charge module illustrated in flowchart 220 of Fig. 9, a fast charge module, such as the fast charge module illustrated in flowchart 225 of Fig. 10, and/or a maintenance charge module, such as the maintenance module illustrated in flowchart 230 of Fig. 11.

In some constructions and in some aspects, each charging module 215-230 is selected by the controller 100 during the charging operation 200 based on certain battery temperature ranges, certain battery voltage ranges and/or certain battery capacity ranges. In some constructions, each module 215-230 is selected by the controller 100 based on the battery characteristics shown in Table 1. In some constructions, the condition "battery temperature" or "temperature of the battery" can include the temperature of the battery taken as a whole (i.e., battery cells, battery components, etc.) and/or the temperature of the battery cells taken individually or collectively. In some constructions, each charging module 215-230 can be based on the same base charging scheme or charging algorithm, such as, for example, a full charge current, as discussed below.



**Operation for Charging Li-based Batteries**

Battery Voltage (V/cell)	Battery Temperature (°C)			
	$< T_1$	$T_1$ to $T_2$	$T_2$ to $T_3$	$> T_3$
$< V_1$	No charge. Slow blink for first LED.	Trickle charge. First LED on steady.	Trickle charge. First LED on steady.	No charge. Slow blink for first LED.
$V_1$ to $V_2$	No charge. Slow blink for first LED.	Step charge. First LED on steady until near full charge, then turns off. Second LED blinks near full charge.	Fast charge. First LED on steady until near full charge, then turns off. Second LED blinks near full charge.	No charge. Slow blink for first LED.
$V_2$ to $V_3$	No charge. Slow blink for first LED.	Maintenance charge. Second LED on steady.	Maintenance charge. Second LED on steady.	No charge. Slow blink for first LED.
$> V_3$	No charge. Fast blink for first LED.	No charge. Fast blink for first LED.	No charge. Fast blink for first LED.	No charge. Fast blink for first LED.

Table 1

In some constructions and in some aspects, the charging current applied to the battery 20 during the trickle charge module 215 includes applying a full charge current (e.g., "I") to the battery 20 for a first time period, such as, for example, ten seconds, and then suspending the full charge current for a second time period, such as, for example, 50 seconds. In some constructions, the full charge current is a pulse of charging current approximately at a predefined amplitude. In some constructions, the battery charger 30 only enters the trickle charge module 215 if the battery voltage is less than a first predefined voltage threshold,  $V_1$ .

In some constructions and in some aspects, the charging current applied to the battery 20 during the fast charge module 225 includes applying the full charge current to the battery 20 for a first time period, such as, for example, one second, and then suspending the full charge current for a second time period, such as, for example, 50-ms. In some constructions, the controller 100 sets a back-up timer to a first predefined time limit, such as, for example, approximately two hours. In these constructions, the battery

charger 30 will not implement the fast charge module 225 for the predefined time limit in order to avoid battery damage. In other constructions, the battery charger 30 will shut down (e.g., stop charging) when the predefined time limit expires.

5 In some constructions, the battery charger 30 only enters the fast charge module 225 if the battery voltage is included in a range from the first voltage threshold,  $V_1$ , to a second predefined voltage threshold,  $V_2$ , and the battery temperature falls within a range from a second battery temperature threshold,  $T_2$ , to a third battery temperature threshold,  $T_3$ . In some constructions, the second voltage threshold,  $V_2$ , is greater than the first voltage threshold,  $V_1$ , and the third temperature threshold,  $T_3$ , is greater than the second  
10 temperature threshold,  $T_2$ .

In some constructions and in some aspects, the charging current applied to the battery 20 during the step charge module 220 includes applying the charging current of the fast charge module 225 to the battery 20, but having a duty cycle of one minute charging ("ON"), one minute suspended charging ("OFF"). In some constructions, the controller  
15 100 sets a back-up timer to a second predefined time limit, such as, for example, approximately four hours. In these constructions, the battery charger 30 will not implement the step charge module 220 for the predefined time limit in order to avoid battery damage.

In some constructions, the battery charger 30 only enters the step charge module  
20 220 if the battery voltage is included in a range from the first voltage threshold,  $V_1$ , to the second voltage threshold,  $V_2$ , and the battery temperature falls within a range from the first temperature threshold,  $T_1$ , to the second temperature threshold,  $T_2$ . In some constructions, the second voltage threshold,  $V_2$ , is greater than the first voltage threshold,  $V_1$ , and the second temperature threshold,  $T_2$ , is greater than the first temperature threshold,  $T_1$ .

25 In some constructions and in some aspects, the charging current applied to the battery 20 during the maintenance module 230 includes applying a full charge current to the battery 20 only when the battery voltage falls to a certain predefined threshold. In some constructions, the threshold is approximately 4.05-V/cell +/- 1% per cell. In some constructions, the battery charger 30 only enters the maintenance module 230 if the battery  
30 voltage is included in the range of the second voltage threshold,  $V_2$ , to the third voltage threshold,  $V_3$ , and the battery temperature falls within a range from the first temperature threshold,  $T_1$ , to the third temperature threshold,  $T_3$ .

In some constructions and in some aspects, the controller 100 implements the various charging modules 220-230 based on various battery conditions. In some

constructions, each charging module 220-230 includes the same charging algorithm (e.g., algorithm for applying the full charge current). However, each charging module 220-230 implements, repeats or incorporates the charging algorithm in a different manner. An example of a charging algorithm is the charge current algorithm illustrated in flowchart 5 250 of Fig. 12, as will be discussed below.

As illustrated in Figs. 5a and 5b, the charging operation 200 begins when a battery, such as the battery 20, is inserted or electrically connected to the battery charger 30 at step 305. At step 310, the controller 100 determines if a stable input of power, such as, for example, the power source 130, is applied or connected to the battery charger 30. As 10 indicated in Fig. 5a, the same operation (i.e., step 305 proceeding to step 310) still applies if power is applied after the battery 20 is electrically connected to the battery charger 30.

If the controller 100 determines there is not a stable input of power applied, then the controller 100 does not activate the indicator 110 and no charge is applied to the battery 20 at step 315. In some constructions, the battery charger 30 draws a small 15 discharge current at step 315. In some constructions, the discharge current is approximately less than 0.1-mA.

If the controller 100 determines there is a stable input of power applied to the battery charger 30 at step 310, then the operation 200 proceeds to step 320. At step 320, the controller 100 determines if all the connections between the battery terminals 45, 50 20 and 55 and the battery charger terminals 80, 85 and 90 are stable. If the connections are not stable at step 320, the controller 100 continues to step 315.

If the connections are stable at step 320, the controller 100 identifies the chemistry of the battery 20 via the sense terminal 55 of the battery 20 at step 325. In some constructions, a resistive sense lead from the battery 20, as sensed by the controller 100, 25 indicates that the battery 20 has a chemistry of either NiCd or NiMH. In some constructions, the controller 100 will measure the resistance of the resistive sense lead to determine the chemistry of the battery 20. For example, in some constructions, if the resistance of the sense lead falls in a first range, then the chemistry of the battery 20 is NiCd. If the resistance of the sense lead falls in a second range, then the chemistry of the 30 battery 20 is NiMH.

In some constructions, NiCd batteries and NiMH batteries are charged by the battery charger 30 using a single charging algorithm that is different from a charging algorithm implemented for batteries having Li-based chemistries. In some constructions, the single charging algorithm for NiCd and NiMH batteries is, for example, an existing

charging algorithm for NiCd/NiMH batteries. In some constructions, the battery charger 30 uses the single charging algorithm for charging NiCd batteries and NiMH batteries but ends the charging process for NiCd batteries with a different termination scheme than the termination scheme used to terminate charging for NiMH batteries. In some constructions, the battery charger 30 terminates charging for NiCd batteries when a negative change in the battery voltage (e.g.,  $-\Delta V$ ) is detected by the controller 100. In some constructions, the battery charger 30 terminates charging for NiMH batteries when a change in battery temperature over time (e.g.,  $\Delta T/dt$ ) reaches or exceeds a predefined termination threshold.

In some constructions, the NiCd and/or NiMH batteries are charged using a constant current algorithm. For example, the battery charger 30 can include the same charging circuitry for charging different batteries having differing battery chemistries, such as NiCd, NiMH, Li-ion, and the like. In an exemplary construction, the charger 30 can use the charging circuitry to apply the same full charge current to NiCd and NiMH batteries as Li-ion batteries using a constant current algorithm instead of pulse charging. In another exemplary construction, the battery charger 30 can be capable of scaling the full charge current through the charging circuitry according to the battery chemistry.

In other constructions, the controller 100 does not determine the exact chemistry of the battery 20. Rather, the controller 100 implements a charging module that can effectively charge both NiCd batteries and NiMH batteries.

In other constructions, the resistance of the sense lead could indicate that the battery 20 has a Li-based chemistry. For example, if the resistance of the sense lead falls in a third range, then the chemistry of the battery 20 is Li-based.

In some constructions, a serial communication link between the battery charger 30 and the battery 20 established through the sense terminals 55 and 90 indicates that the battery 20 has a Li-based chemistry. If a serial communication link is established at step 320, then a microprocessor or controller, such as the controller 64, in the battery 20 sends information regarding the battery 20 to the controller 100 in the battery charger 30. Such information transferred between the battery 20 and battery charger 30 can include battery chemistry, nominal battery voltage, battery capacity, battery temperature, individual cell voltages, number of charging cycles, number of discharging cycles, status of a protection circuit or network (e.g., activated, disabled, enabled, etc.), etc.

At step 330, the controller 100 determines if the chemistry of the battery 20 is Li-based or not. If the controller 100 determines that the battery 20 has a chemistry of either

NiCd or NiMH at step 330, then the operation 200 proceeds to the NiCd/NiMH charging algorithm at step 335.

5 If the controller 100 determines that the battery 20 has a chemistry that is Li-based at step 330, then the operation 200 proceeds to step 340. At step 340, the controller 100 resets any battery protection circuit, such as, for example, a switch, included in the battery 20 and determines the nominal voltage of the battery 20 via the communication link. At step 345, the controller 100 sets the charger analog-to-digital converter ("A/D") to the appropriate level based on nominal voltage.

10 At step 350, the controller 100 measures the present voltage of the battery 20. Once a measurement is made, the controller 100 determines if the voltage of the battery 20 is greater than 4.3-V/cell at step 355. If the battery voltage is greater than 4.3-V/cell at step 355, then the operation 200 proceeds to the defective pack module 205 at step 360. The defective pack module 205 will be discussed below.

15 If the battery voltage is not greater than 4.3-V/cell at step 355, then the controller 100 measures the battery temperature at step 365 and determines if the battery temperature falls below  $-10^{\circ}\text{C}$  or exceeds  $65^{\circ}\text{C}$  at step 370. If the battery temperature is below  $-10^{\circ}\text{C}$  or is above  $65^{\circ}\text{C}$  at step 370, then the operation 200 proceeds to the temperature out-of-range module 210 at step 375. The temperature out-of-range module 210 will be discussed below.

20 If the battery temperature is not below  $-10^{\circ}\text{C}$  or does not exceed  $65^{\circ}\text{C}$  at step 370, then the controller 100 determines at step 380 (shown in Fig. 5b) if the battery temperature falls between  $-10^{\circ}\text{C}$  and  $0^{\circ}\text{C}$ . If the battery temperature falls between  $-10^{\circ}\text{C}$  and  $0^{\circ}\text{C}$  at step 380, the operation 200 proceeds to step 385. At step 385, the controller 100 determines if the battery voltage is less than 3.5-V/cell. If the battery voltage is less than 25 3.5-V/cell, the operation 200 proceeds to the trickle charge module 215 at step 390. The trickle charge module 215 will be discussed below.

If the battery voltage is not less than 3.5-V/cell at step 385, the controller 100 determines if the battery voltage is included in the voltage range of 3.5-V/cell to 4.1-V/cell at step 395. If the battery voltage is not included in the voltage range of 3.5-V/cell to 4.1-V/cell at step 395, then the operation 200 proceeds to the maintenance module 230 at step 30 400. The maintenance module 230 will be discussed below.

If the battery voltage is included in the voltage range of 3.5-V/cell to 4.1-V/cell at step 395, the controller 100 clears a counter, such as a charge counter, at step 405. Once the charge counter is cleared at step 405, the operation 200 proceeds to the step charge

module 220 at step 410. The step charge module 220 and charge counter will be discussed below.

Referring back to step 380, if the battery temperature is not included within the range of  $-10^{\circ}\text{C}$  and  $0^{\circ}\text{C}$ , the controller 100 determines if the battery voltage is less than 3.5-V/cell at step 415. If the battery voltage is less than 3.5-V/cell at step 415, the operation 200 proceeds to the trickle charge module 215 at step 420.

If the battery voltage is not less than 3.5-V/cell at step 415, the controller 100 determines if the battery voltage is included in the voltage range of 3.5-V/cell to 4.1-V/cell at step 425. If the battery voltage is not included in the voltage range of 3.5V/cell to 4.1-V/cell at step 425, then the operation 200 proceeds to the maintenance module 230 at step 430.

If the battery voltage is included in the voltage range of 3.5-V/cell to 4.1-V/cell at step 425, the controller 100 clears a counter, such as the charge counter, at step 435. Once the charge counter is cleared at step 435, the operation 200 proceeds to the fast charge module 225 at step 440. The fast charge module 225 will be discussed below.

Fig. 6 is a flowchart illustrating the operation of the defective pack module 205. Operation of the module 205 begins when the main charging operation 200 enters the defective pack module 205 at step 460. The controller 100 interrupts the charging current at step 465 and activates the indicator 110, such as the first LED, at step 470. In the illustrated construction, the controller 100 controls the first LED to blink at a rate of approximately 4-Hz. Once the indicator 110 is activated in step 470, the module 205 ends at step 475, and the operation 200 may also end.

Fig. 7 is a flowchart illustrating the operation of the temperature out-of-range module 210. Operation of the module 210 begins when the main charging operation 200 enters the temperature out-of-range module 210 at step 490. The controller 100 interrupts the charging current at step 495 and activates the indicator 110, such as the first LED, at step 500. In the construction illustrated, the controller 100 controls the first LED to blink at a rate of approximately 1-Hz to indicate to a user that the battery charger 30 is currently in the temperature-out-of-range module 210. Once the indicator 110 is activated in step 500, operation 200 exits the module 210 and proceeds to where the operation 200 left off.

Fig. 8 is a flowchart illustrating the trickle charge module 215. Operation of the module 215 begins when the main charging operation 200 enters the trickle charge module 215 at step 520. The controller 100 activates the indicator 110, such as the first LED 115, at step 525 to indicate to a user that the battery charger 30 is currently charging the battery

20. In the illustrated construction, the controller 100 activates the first LED 115 so that it appears to be constantly on.

Once the indicator 110 is activated in step 525, the controller 100 initializes a counter, such as a trickle charge count counter, at step 530. In the construction illustrated,  
5 the trickle charge count counter has a count limit of twenty.

At step 540, the controller 100 begins to apply ten one second ("1-s") full current pulses to the battery 20 and then suspends charging for fifty seconds ("50-s"). In some constructions, there are 50-ms time intervals between the 1-s pulses.

At step 545, the controller 100 measures the battery voltage when a charging  
10 current is applied to the battery 20 (e.g., current on-times) to determine if the battery voltage exceeds 4.6-V/cell. If the battery voltage exceeds 4.6-V/cell during current on-times at step 545, the module 215 proceeds to the defective pack module 205 at step 550 and would end at step 552. If the battery voltage does not exceed 4.6-V/cell during current on-times at step 545, the controller 100 measures the battery temperature and the battery  
15 voltage when a charging current is not applied to the battery 20 (e.g., current off-times) at step 555.

At step 560, the controller 100 determines if the battery temperature falls below -10°C or exceeds 65°C. If the battery temperature is below -10°C or is above 65°C at step 560, then the module 215 proceeds to the temperature out-of-range module 210 at step 565  
20 and would end at step 570. If the battery temperature is not below -10°C or is not above 65°C at step 560, then the controller 100 determines if the battery voltage is included in the range of 3.5-V/cell to 4.1-V/cell at step 575.

If the battery voltage is included in the range of 3.5-V/cell to 4.1-V/cell at step 575, then the controller 100 determines if the battery temperature is included in the range of -10°C to 0°C at step 580. If the battery temperature is included in the range of -10°C to  
25 0°C at step 580, then the module 215 proceeds to the step charge module 220 at step 585. If the battery temperature is not included in the range of -10°C to 0°C at step 580, then the module 215 proceeds to the fast charge module 225 at step 590.

If the battery voltage is not included in range of 3.5-V/cell to 4.1-V/cell at step  
30 575, then the controller 100 increments the trickle charge count counter at step 595. At step 600, the controller 100 determines if the trickle charge count counter equals the counter limit, such as for example, twenty. If the counter does not equal the counter limit at step 600, the module 215 proceeds to step 540. If the counter does equal the count limit

at step 600, the module 215 proceeds to the defective pack module 205 at step 605 and would end at step 610.

Fig. 9 is a flowchart illustrating the step charge module 220. Operation of the module 220 begins when the main charging operation 200 enters the step charge module 220 at step 630. The controller 100 activates the indicator 110, such as the first LED 115, at step 635 to indicate to a user that the battery charger 30 is currently charging the battery 20. In the illustrated construction, the controller 100 activates the first LED 115 so that it appears to be constantly on.

At step 640, the controller 100 starts a first timer or charge-on timer. In the illustrated construction, the charge-on timer counts down from one minute. At step 645, the module 220 proceeds to the charge current algorithm 250. Once the charge current algorithm 250 is performed, the controller 100 determines if the charge count equals the count limit, such as, for example, 7,200, at step 650. If the charge count equals the count limit at step 650, the module 220 proceeds to the defective pack module 205 at step 655 and the module 220 would end at step 660.

If the charge count does not equal the count limit at step 650, the controller 100 determines if the waiting time between current pulses (as will be discussed below) is greater than or equal to a first waiting time threshold, such as, for example, two seconds, at step 665. If the waiting time is greater than or equal to the first waiting time threshold at step 665, the controller 100 activates the indicator 110 at step 670, such as, for example, turns off the first LED 115 and activates the second LED 120 to blink at approximately 1-Hz. If the waiting time is not greater than or equal to the first waiting time threshold at step 665, the module 220 proceeds to step 690, which is discussed below.

Once the indicator 110 is activated at step 670, the controller 100 determines if the waiting time between current pulses is greater than or equal to a second waiting time threshold, such as, for example, fifteen seconds, at step 675. If the waiting time is greater than or equal to the second waiting time threshold at step 675, the controller 100 changes the indicator 110 at step 680, such as, for example, activates the second LED 120 such that the second LED 120 appears to be on constantly. The module 220 then proceeds to the maintenance module 230 at step 685.

If the waiting time is not greater than or equal to the second waiting time threshold at step 675, the controller 100 determines if the battery temperature is greater than 0°C at step 690. If the battery temperature is greater than 0°C at step 690, the module 220 proceeds to the fast charge module 225 at step 695. If the battery temperature is not



greater than 0°C at step 690, the controller 100 determines if the charge-on timer has expired at step 700.

If the charge-on timer has not expired at step 700, the module 220 proceeds to the charge current algorithm 250 at step 645. If the charge-on timer has expired at step 700, the controller 100 activates a second timer or a charge-off timer at step 705 and suspends charging. At step 710, the controller 100 determines if the charge-off timer has expired. If the charge-off timer has not expired at step 710, the controller 100 waits for a predefined amount of time at step 715 and then proceeds back to step 710. If the charge-off timer has expired at step 710, the module 220 proceeds back to step 640 to start the charge-on timer again.

Fig. 10 is a flowchart illustrating the fast charge module 225. Operation of the module 225 begins when the main charging operation 200 enters the fast charge module 220 at step 730. The controller 100 activates the indicator 110, such as the first LED 115, at step 735 to indicate to a user that the battery charger 30 is currently charging the battery 20. In the illustrated construction, the controller 100 activates the first LED 115 so that it appears to be constantly on.

At step 740, the module 225 proceeds to the charge current algorithm 250. Once the charge current algorithm 250 is performed, the controller 100 determines if the charge count equals the count limit (e.g., 7,200) at step 745. If the charge count equals the count limit at step 650, the module 220 proceeds to the defective pack module 205 at step 750 and the module 220 would end at step 755.

If the charge count does not equal the count limit at step 745, the controller 100 determines if the waiting time between current pulses is greater than or equal to the first waiting time threshold (e.g., two seconds) at step 760. If the waiting time is greater than or equal to the first waiting time threshold at step 760, the controller 100 activates the indicator 110 at step 765, such as, for example, turns off the first LED 115 and activates the second LED 120 to blink at approximately 1-Hz. If the waiting time is not greater than or equal to the first waiting time threshold at step 760, the module 225 proceeds to step 785, which is discussed below.

Once the indicator 110 is activated at step 765, the controller 100 determines if the waiting time between current pulses is greater than or equal to a second waiting time threshold (e.g., fifteen seconds) at step 770. If the waiting time is greater than or equal to the second waiting time threshold at step 770, the controller 100 changes the indicator 110 at step 775, such as, for example, activates the second LED 120 such that the second LED

120 appears to be on constantly. The module 225 then proceeds to the maintenance module 230 at step 780.

If the waiting time is not greater than or equal to the second waiting time threshold at step 770, the controller 100 determines if the battery temperature is included in the range of  $-20^{\circ}\text{C}$  to  $0^{\circ}\text{C}$  at step 785. If the battery temperature is included in the range at step 785, the module 225 proceeds to the step charge module 220 at step 790. If the battery temperature is not included in the range at step 785, the module 225 proceeds back to the charge current algorithm 250 at step 740.

Fig. 11 is a flowchart illustrating the maintenance module 230. Operation of the module 230 begins when the main charging operation 200 enters the maintenance module 230 at step 800. The controller 100 determines if the battery voltage is included within the range of 3.5-V/cell to 4.05-V/cell at step 805. If the battery voltage is not included in the range at step 805, the controller 100 continues to stay in step 805 until the battery voltage is included in the range. Once the battery voltage is included in the range at step 805, the controller 100 initializes a maintenance timer at step 810. In some constructions, the maintenance timer counts down from thirty minutes.

At step 815, the controller 100 determines if the battery temperature falls below  $-20^{\circ}\text{C}$  or exceeds  $65^{\circ}\text{C}$ . If the battery temperature falls below  $-20^{\circ}\text{C}$  or exceeds  $65^{\circ}\text{C}$  at step 815, the module 230 proceeds to the temperature out-of-range module 210 at step 820 and the module would end at step 825. If the battery temperature does not fall below  $-20^{\circ}\text{C}$  or does not exceed  $65^{\circ}\text{C}$  at step 815, the module 230 proceeds to the charge current algorithm 250 at step 830.

Once the charge current algorithm 250 is performed at step 830, the controller 100 determines if the maintenance timer has expired at step 835. If the maintenance timer has expired, the module 230 proceeds to the defective pack module 840 at step 840, and the module 230 would end at step 845. If the maintenance timer has not expired at step 835, the controller 100 determines if the waiting time between the current pulses is greater than or equal to a first predefined maintenance waiting time period, such as, for example, fifteen seconds, at step 850.

If the waiting time is greater than the first predefined maintenance waiting time period at step 850, the module 230 proceeds to step 805. If the waiting time is not greater than or equal to the first predefined maintenance waiting time period at step 850, the module 230 proceeds to the charge current algorithm 250 at step 830. In some

constructions, the battery charger 30 will remain in the maintenance module 230 until the battery pack 20 is removed from the battery charger 30.

Fig. 12 is a flowchart illustrating the base charge scheme or charge current algorithm 250. Operation of the module 250 begins when the other modules 220-230 or main charging operation 200 enters the charge current algorithm 250 at step 870. The controller 100 applies a full current pulse for approximately one second at step 875. At step 880, the controller 100 determines if the battery voltage 880 is greater than 4.6-V/cell when current is being applied to the battery 20.

If the battery voltage is greater than 4.6-V/cell at step 880, then the algorithm 250 proceeds to the defective pack module 205 at step 885, and the algorithm 250 would end at step 890. If the battery voltage is not greater than 4.6-V/cell at step 880, the controller 100 interrupts the charging current, increments a counter, such as the charge current counter, and stores the count value at step 895.

At step 900, the controller 100 determines if the battery temperature falls below  $-20^{\circ}\text{C}$  or exceeds  $65^{\circ}\text{C}$ . If the battery temperature falls below  $-20^{\circ}\text{C}$  or exceeds  $65^{\circ}\text{C}$  at step 900, the algorithm 250 proceeds to the temperature out-of-range module 205 at step 905, and the algorithm 250 will terminate at step 910. If the battery temperature does not fall below  $-20^{\circ}\text{C}$  or does not exceed  $65^{\circ}\text{C}$  at step 900, the controller 100 measures the battery voltage when the charging current is not being supplied to the battery 20 at step 915.

At step 920, the controller 100 determines if the battery voltage is less than 4.2-V/cell. If the battery voltage is less than 4.2-V/cell at step 920, the algorithm 250 proceeds to step 875. If the battery voltage is not less than 4.2-V/cell at step 920, the controller 100 waits until the battery voltage approximately equals 4.2-V/cell at step 925. Also at step 925, the controller 100 stores the waiting time. The algorithm 250 ends at step 930.

In another construction, the full charge current or full charge pulse applied by the battery charger 30 can be scaled according to the individual cell voltages in the battery 20. This implementation will be described with respect to Figs. 4 and 16.

As shown in Fig. 4, the controller 100 in the battery charger 30 can receive and transmit information from and to the microcontroller 64 in the battery 20. In some constructions, the microcontroller 64 can monitor various battery characteristics during charging, including the voltages or present state of charge of each battery cells 60, either automatically or in response to a command from the battery charger 30. The microcontroller 64 can monitor certain battery characteristics and process or average

measurements during periods of charge current (i.e., “current on” time periods)  $T_{on}$ . In some constructions, the current on time period can be approximately one second (“1-s”). During periods of no charge current (i.e., “current off” time periods)  $T_{off}$ , information regarding certain battery characteristics (e.g., cell voltages or cell state of charges) can be transferred from the battery 20 to the charger 30. In some constructions, the current off time period  $T_{off}$  is approximately 50 ms. The battery charger 30 can process the information sent from the battery 20 and modify the current on time periods  $T_{on}$  accordingly. For example, if one or more battery cells 60 have a higher present state of charge than the remaining battery cells 60, then the battery charger 30 may decrease subsequent current on time periods  $T_{on}$  in order to avoid overcharging the one or more higher battery cells.

In some constructions, the battery charger 30 may compare each individual cell voltage to an average cell voltage, and if the difference between the individual cell voltage and the average cell voltage equals or exceeds a predefined threshold (e.g., an imbalance threshold) then the charger 30 may identify the cell as being a higher state of charge cell. The battery charger 30 may modify the current on time period  $T_{on}$ . In other constructions, the battery charger 30 may estimate the state of charge for a particular battery cell (such as a battery cell identified as a higher voltage cell) during current on time periods based on the information received from the battery 20. In these constructions, if the estimation of the present state of charge for the cell exceeds a threshold, then the battery charger 30 may modify the duration of the current on time period  $T_{on}$ .

For example, as shown in Fig. 16, the battery charger 30 can command the battery 20 to average the cell voltage measurements taken during the next current on time  $T_{on1}$ . The command may be sent during the first current off time period  $T_{off1}$ . Accordingly, during the first current on time  $T_{on1}$ , the microcontroller 64 measures and averages the cell voltages as well as other battery parameters. During the next current off time  $T_{off2}$ , the battery 20 can transmit the averaged measurements to the battery charger 30. In some constructions, the battery 20 can send eight averaged measurements such as, for example, an averaged pack state of charge measurement and an averaged individual cell state of charge for each of the seven battery cells 60. For example, the battery 20 may send the following information: cell 1 14%, cell 2 14%, cell 3 15%, cell 4 14%, cell 5 16%, cell 6 14%, cell 7 14%, and pack (e.g., cells 1-7) voltage 29.96 V. In this example, the battery charger 30 identifies cell 5 as being a higher battery cell. The charger 30 also records the battery voltage as measured by the both the battery microcontroller 64 and the battery

charger 30. In this example, the battery charger 30 measures the battery voltage as approximately 30.07 V. The battery charger 30 computes the difference in battery voltage measurements (e.g., 110 mV), and determines the voltage drop across the terminals and leads as approximately 110 mV.

5            During the subsequent current on time period  $T_{on2}$ , the battery charger 30 “estimates” the voltage of cell 5. For example, the battery charger 30 samples measurements of the voltage of the battery 20, and for each battery voltage measurement, estimates the state of charge for cell 5 according to the following equation:

$$10 \quad (V_{\text{battery/ch}} - V_{\text{terminals}}) * V_{\text{cell}}$$

wherein  $V_{\text{battery/ch}}$  is the voltage of the battery 20 as measurement by the charger 30,  $V_{\text{terminals}}$  is the voltage drop across the terminals (e.g., 110 mV), and  $V_{\text{cell}}$  is the voltage of the cell being estimated as a percentage of the battery voltage. If the estimation of cell 5's voltage exceeds a threshold, then the battery charger 30 may modify the subsequent current on time period  $T_{\text{on}3}$ . As shown in Fig. 16, the charger 30 identifies cell 5 as being a high battery cell, and modifies the subsequent current on time period  $T_{\text{on}3}$  to be approximately 800 ms. Accordingly, the length  $T_2$  of the current on time period  $T_{\text{on}3}$  is less than the length  $T_1$  of the previous current on time periods  $T_{\text{on}1}$  and  $T_{\text{on}2}$ .

20 In some constructions, the charger 30 continues to set the subsequent current on  
time periods (e.g.,  $T_{on4-5}$ ) to approximately the length  $T_2$  of the previous current on time  
period  $T_{on3}$  (e.g., 800 ms). If cell 5 (or another cell) continues to be identified as a high  
cell, then the charger 30 can modify the length the subsequent current on time period (e.g.,  
 $T_{on6}$ ) from length  $T_2$  (e.g., approximately 800 ms) to  $T_3$  (e.g., approximately 600ms), for  
25 example.

A further schematic diagram of a battery 20' is schematically illustrated in Fig. 13. The battery 20' is similar to the battery 20, and common elements are identified by the same reference number "".

In some constructions, the circuit 62' includes an electrical component such as, for example, an identification resistor 950, and the identification resistor 950 can have a set resistance. In other constructions, the electrical component may be a capacitor, an inductor, a transistor, a semiconducting element, an electrical circuit or another component having a resistance or capable of sending an electrical signal such as, for example, a microprocessor, a digital logic component and the like. In the illustrated construction, the

resistance value of the identification resistor 950 can be chosen based on characteristics of the battery 20', such as the nominal voltage and the chemistry of the battery cell(s) 60'. A sense terminal 55' can electrically connect to the identification resistor 950.

5 The battery 20', shown schematically in Fig. 13, can electrically connect to an electrical device, such as a battery charger 960 (also shown schematically). The battery charger 960 can include a positive terminal 964, a negative terminal 968 and a sense terminal 972. Each terminal 964, 968, 972 of the battery charger 960 can electrically connect to the corresponding terminal 45', 50', 55' (respectively), of the battery 20'. The battery charger 960 also can include a circuit having electrical components, such as, for  
10 example, a first resistor 976, a second resistor 980, a solid-state electronic device or semiconductor 984, a comparator 988 and a processor, microcontroller or controller (not shown). In some constructions, the semiconductor 984 can include a transistor capable of operating in saturation or an "ON" state and capable of operating in cut-off or an "OFF" state. In some constructions, the comparator 988 can be a dedicated voltage monitoring  
15 device, a microprocessor or a processing unit. In other constructions, the comparator 988 can be included in the controller (not shown).

In some constructions, the controller (not shown) can be programmed to identify the resistance value of the electrical component in the battery 20', such as the identification resistor 958. The controller can also be programmed to determine one or  
20 more characteristics of the battery 20', such as, for example, the battery chemistry and the nominal voltage of the battery 20'. As previously mentioned, the resistance value of the identification resistor 958 may correspond to a dedicated value associated with one or more certain battery characteristics. For example, the resistance value of the identification resistor 958 can be included in a range of resistance values corresponding to the chemistry  
25 and to the nominal voltage of the battery 20'.

In some constructions, the controller can be programmed to recognize a plurality of resistance ranges of the identification resistor 958. In these constructions, each range corresponds to one battery chemistry, such as, for example, NiCd, NiMH, Li-ion, and the like. In some constructions, the controller can recognize additional resistance ranges, each  
30 corresponding to another battery chemistry or another battery characteristic.

In some constructions, the controller can be programmed to recognize a plurality of voltage ranges. The voltages included in the voltage ranges can be dependent on or correspond to the resistance value of the identification resistor 958, such that the controller can determine the value of the resistor 958 based on the measured voltage.

In some constructions, the resistance value of the identification resistor 958 can be further chosen to be unique for each possible nominal voltage value of the battery 20'. For example, in one range of resistance values, a first dedicated resistance value can correspond to a nominal voltage of 21 V, a second dedicated resistance value can  
5 correspond to a nominal voltage of 16.8 V, and a third dedicated resistance value can correspond to a nominal voltage of 12.6 V. In some constructions, there can be more or fewer dedicated resistance values, each corresponding to another possible nominal voltage of the battery 20' associated with the resistance range.

In an exemplary implementation, the battery 20' electrically connects to the battery  
10 charger 960. To identify a first battery characteristic, the semiconductor 984 switches to the "ON" state under the control of additional circuitry (not shown). When the semiconductor 984 is in the "ON" state, the identification resistor 958 and resistors 976 and 980 create a voltage divider network. The network establishes a voltage  $V_A$  at a first reference point 992. If the resistance value of the resistor 980 is significantly lower than  
15 the resistance value of the resistor 976, then the voltage  $V_A$  will be dependent upon the resistance values of the identification resistor 958 and the resistor 980. In this implementation, the voltage  $V_A$  is in a range determined by the resistance value of the identification resistor 958. The controller (not shown) measures the voltage  $V_A$  at the first reference point 992 and determines the resistance value of the identification resistor 958  
20 based on the voltage  $V_A$ . In some constructions, the controller compares the voltage  $V_A$  to a plurality of voltage ranges to determine the battery characteristic.

In some constructions, the first battery characteristic to be identified can include the battery chemistry. For example, any resistance value below 150 k ohms may indicate that the battery 20' has a chemistry of NiCd or NiMH, and any resistance value  
25 approximately 150 k ohms or above may indicate that the battery 20' has a chemistry of Li or Li-ion. Once the controller determines and identifies the chemistry of the battery 20', an appropriate charging algorithm or method may be selected. In other constructions, there are more resistance ranges which each correspond to another battery chemistry than in the above example.

30 Continuing with the exemplary implementation, to identify a second battery characteristic, the semiconductor 984 switches to the "OFF" state under the control of the additional circuitry. When the semiconductor 984 switches to the "OFF" state, the identification resistor 958 and the resistor 976 create a voltage divider network. The voltage  $V_A$  at the first reference point 992 is now determined by the resistance values of

the identification resistor 958 and the resistor 976. The resistance value of the identification resistor 958 is chosen such that, when the voltage  $V_{BATT}$  at a second reference point 880 substantially equals the nominal voltage of the battery 20', the voltage  $V_A$  at the first reference point 992 substantially equals a voltage  $V_{REF}$  at a third reference point 996. If the voltage  $V_A$  at the first reference point 992 exceeds the fixed voltage  $V_{REF}$  at the third reference point 996, an output  $V_{OUT}$  of the comparator 988 changes state. In some constructions, the output  $V_{OUT}$  can be used to terminate charging or to serve as an indicator to commence additional functions, such as a maintenance routine, an equalization routine, a discharging function, additional charging schemes, and the like. In some constructions, voltage  $V_{REF}$  can be a fixed reference voltage.

In some constructions, the second battery characteristic to be identified can include a nominal voltage of the battery 20'. For example, a general equation for calculating the resistance value for the identification resistor 958 can be:

$$R_{100} = \frac{V_{REF} \cdot R_{135}}{V_{BATT} - V_{REF}}$$

wherein  $R_{100}$  is the resistance value of the identification resistor 958,  $R_{135}$  is the resistance value of the resistor 976,  $V_{BATT}$  is the nominal voltage of the battery 20' and  $V_{REF}$  is a fixed voltage, such as, for example, approximately 2.5 V. For example, in the range of resistance values for the Li-ion chemistry (set forth above), a resistance value of approximately 150 k ohms for the identification resistor 958 can correspond to a nominal voltage of approximately 21 V, a resistance value of approximately 194 k ohms can correspond to a nominal voltage of approximately 16.8 V, and a resistance value of approximately 274.7 k ohms can correspond to a nominal voltage of approximately 12.6 V. In other constructions, more or fewer dedicated resistance values may correspond to additional or different battery pack nominal voltage values.

In the illustrated construction, both the identification resistor 958 and the third reference point 996 may be situated on the "high" side of a current sense resistor 1000. Positioning the identification resistor 958 and the third reference point 996 in this manner can reduce any relative voltage fluctuations between  $V_A$  and  $V_{REF}$  when a charging current is present. Voltage fluctuations may appear in voltage  $V_A$  if the identification resistor 958 and the third reference point 996 were referenced to ground 1004 and a charging current was applied to the battery 20'.

In some constructions, the battery charger 960 can also include a charger control function. As previously discussed, when the voltage  $V_A$  substantially equals the voltage



$V_{REF}$  (indicative of voltage  $V_{BATT}$  equaling the nominal voltage of battery 20'), the output  $V_{OUT}$  of the comparator 988 changes state. In some constructions, the charging current is no longer supplied to the battery 20' when the output  $V_{OUT}$  of the comparator 988 changes state. Once the charging current is interrupted, the battery voltage  $V_{BATT}$  begins to

5 decrease. When voltage  $V_{BATT}$  reaches a low threshold, the output  $V_{OUT}$  of the comparator 860 changes state again. In some constructions, the low threshold of voltage  $V_{BATT}$  is determined by a resistance value of a hysteresis resistor 1008. The charging current is reestablished once the output  $V_{OUT}$  of the comparator 988 changes state again. In some constructions, this cycle repeats for a predefined amount of time as determined by the

10 controller or repeats for a certain amount of state changes made by the comparator 988. In some constructions, this cycle repeats until the battery 20' is removed from the battery charger 960.

In some constructions and in some aspects, a battery, such as the battery 20 shown in Fig. 17, can become so discharged that the battery cells 60 may not have enough voltage to communicate with a battery charger 30. As shown in Fig. 17, the battery 20 can include one or more battery cells 60, a positive terminal 1105, a negative terminal 1110 and one or more sense terminals 1120a and 1120b (as shown in Fig. 17, the second sense terminal or activation terminal 120b may or may not be included in the battery 20). The battery 20 can also include a circuit 1130 including a microcontroller 1140.

As shown in Fig. 17, the circuit 1130 can include a semiconducting switch 1180 that interrupts the discharging current when the circuit 1130 (e.g., the microprocessor 1140) determines or senses a condition above or below a predetermined threshold (i.e., an “abnormal battery condition”). In some constructions, the switch 1180 includes an interruption condition in which current from or to the battery 20 is interrupted, and an allowance condition in which current from or to the battery 20 is allowed. In some constructions, an abnormal battery condition can include, for example, high or low battery cell temperature, high or low battery state of charge, high or low battery cell state of charge, high or low discharge current, high or low charge current, and the like. In the illustrated constructions, the switch 1180 includes a power FET or a metal-oxide semiconductor FET (“MOSFET”). In other constructions, the circuit 1130 can include two switches 1180. In these constructions, the switches 1180 can be arranged in parallel. Parallel switches 1180 can be included in battery packs supplying a high average discharge current (such as, for example, the battery 20 supplying power to a circular saw, a driver drill, and the like).

In some constructions, once the switch 1180 becomes non-conducting, the switch 1180 may not reset even if the abnormal condition is no longer detected. In some constructions, the circuit 1130 (e.g., the microprocessor 1140) may reset the switch 180 only if an electrical device, such as, for example, a battery charger 30, instructs the microprocessor 1140 to do so. As mentioned previously, the battery 20 may become so discharged that the battery cells 60 may not have enough voltage in order to power the microprocessor 1140 to communicate with a battery charger 30.

In some constructions, if the battery 20 can not communication with the charger 30, the battery charger 30 can supply a small charge current though the body diode 1210 of the switch 1180 to slowly charge the battery cells 60. Once the cells 60 receive enough charge current to power the microprocessor 1140, the microprocessor 1140 can change the state of the switch 1180. That is, the battery 50 can be charged even when the switch 1180

is in the non-conducting state. As shown in Fig. 17, the switch 180 can include the body diode 1210, which, in some constructions, is integral with a MOSFET and other transistors. In other constructions, the diode 1210 can be electrically connected in parallel with the switch 1180.

5        In some constructions, if the battery 20 can not communication with the charger 30, the battery charger 30 can apply a small average current through a sense lead such as, for example, the sense lead 120a or the dedicated activation terminal 120b. The current may charge a capacitor 1150, which in turn can supply enough voltage to the microprocessor 1140 to enable operation.

10        The constructions described above and illustrated in the figures are presented by way of example only and are not intended as a limitation upon the concepts and principles of the present invention. As such, it will be appreciated by one having ordinary skill in the art that various changes in the elements and their configuration and arrangement are possible without departing from the spirit and scope of the present invention.

15

**CLAIMS**

**We claim:**

1.       An electrical combination comprising:  
5               a first battery having a Lithium-based chemistry, the first battery having a first nominal voltage in a nominal voltage range;  
              a second battery having a Lithium-based chemistry, the second battery having a second nominal voltage, the second nominal voltage being different than the first nominal voltage and being outside of the nominal voltage range; and  
10             a battery charger operable to charge the first battery and the second battery.
2.       The electrical combination as set forth in Claim 1 wherein the first battery includes an identification component having a value representing one of the first nominal voltage and the nominal voltage range, and wherein the charger is operable to identify the  
15       value of the identification component.
3.       The electrical combination as set forth in Claim 2 wherein the first battery includes a battery controller, the identification component including the battery controller.
- 20       4.       The electrical combination as set forth in Claim 2 wherein the first battery includes a chemistry identification component having a value representing the Lithium-based chemistry of the first battery.
- 25       5.       The electrical combination as set forth in Claim 4 wherein the first battery includes a battery controller, the chemistry identification component including the battery controller.
- 30       6.       The electrical combination as set forth in Claim 4 wherein the charger includes a controller operable to identify the value of the chemistry identification component.
7.       The electrical combination as set forth in Claim 2 wherein the charger includes a controller operable to identify the value of the identification component.

8. The electrical combination as set forth in Claim 7 wherein the controller is operable to control a supply of charging current to charge a battery.

5 9. The electrical combination as set forth in Claim 7 wherein the controller is operable to monitor a battery characteristic.

10 10. The electrical combination as set forth in Claim 9 wherein the battery characteristic includes a battery voltage.

11. The electrical combination as set forth in Claim 9 wherein the controller is operable to control a charging function.

15 12. The electrical combination as set forth in Claim 11 wherein the charging function includes one of termination of charging of the first battery and termination of a charging mode of charging the first battery.

20 13. The electrical combination as set forth in Claim 11 wherein the charging function includes one of initiation of charging of the first battery and initiation of a charging mode of charging the first battery.

25 14. The electrical combination as set forth in Claim 11 wherein the controller selects a battery characteristic threshold for the charging function when the controller identifies the value of the identification component.

15. The electrical combination as set forth in Claim 14 wherein the battery characteristic threshold includes a first battery voltage threshold.

30 16. The electrical combination as set forth in Claim 15 wherein the first battery voltage threshold is related to one of the first nominal voltage and the nominal voltage range.

17. The electrical combination as set forth in Claim 14 wherein the second nominal voltage is in a second nominal voltage range, the second nominal voltage range being different than the first nominal voltage range.

5 18. The electrical combination as set forth in Claim 17 wherein the second battery includes a second identification component having a second value representing one of the second nominal voltage and the second nominal voltage range, wherein the charger is operable to identify the second value of the second identification component, the controller selecting a second battery characteristic threshold for the charging function  
10 when the controller identifies the second value of the second identification component, the second battery characteristic threshold being different than the first battery characteristic threshold.

15 19. The electrical combination as set forth in Claim 18 wherein the charging function includes one of termination of charging of the second battery and termination of a charging mode of charging the second battery.

20 20. The electrical combination as set forth in Claim 18 wherein the charging function includes one of initiation of charging of the second battery and initiation of a charging mode of charging the second battery.

25 21. The electrical combination as set forth in Claim 18 wherein the battery characteristic threshold includes a first battery voltage threshold, and wherein the second battery characteristic threshold includes a second battery voltage threshold, the second battery voltage threshold being different than the first battery voltage threshold.

30 22. The electrical combination as set forth in Claim 21 wherein the second battery voltage threshold is related to one of the second nominal voltage and the second nominal voltage range.

23. The electrical combination as set forth in Claim 1 wherein the second nominal voltage is in a second nominal voltage range, the second nominal voltage range being different than the first nominal voltage range.

24. The electrical combination as set forth in Claim 23 wherein the second battery includes an identification component having a value representing one of the second nominal voltage and the second nominal voltage range, and wherein the charger is operable to identify the value of the identification component.

5

25. The electrical combination as set forth in Claim 24 wherein the second battery includes a battery controller, the identification component including the battery controller.

10

26. The electrical combination as set forth in Claim 24 wherein the second battery includes a chemistry identification component having a value representing the Lithium-based chemistry of the first battery.

15

27. The electrical combination as set forth in Claim 26 wherein the second battery includes a battery controller, the chemistry identification component including the battery controller.

20

28. The electrical combination as set forth in Claim 26 wherein the charger includes a controller operable to identify the value of the chemistry identification component.

29. A method of charging a battery, a first battery having a Lithium-based chemistry, the first battery having a first nominal voltage in a first nominal voltage range, a second battery having a Lithium-based chemistry, the second battery having a second nominal voltage in a second nominal voltage range, the second nominal voltage being  
5 different than the first nominal voltage, the second nominal voltage range being different than the first nominal voltage range, a battery charger being operable to charge the first battery and the second battery, said method comprising the acts of:

electrically connecting the battery charger and the first battery;

charging the first battery;

10 electrically connecting the battery charger and the second battery; and  
charging the second battery.

30. The method as set forth in Claim 29 and further comprising the act of identifying one of a nominal voltage and a nominal voltage range of one of the first battery  
15 and the second battery.

31. The method as set forth in Claim 29 and further comprising the act of receiving a signal from the battery, the signal being indicative of one of a nominal voltage and a nominal voltage range of one of the first battery and the second battery.  
20

32. The method as set forth in Claim 29 and further comprising the act of identifying the chemistry of one of the first battery and the second battery.

33. The method as set forth in Claim 29 and further comprising the act of receiving a signal from the battery, the signal being indicative of the chemistry of one of  
25 the first battery and the second battery.

34. The method as set forth in Claim 29 and further comprising the act of monitoring a battery characteristic.  
30

35. The method as set forth in Claim 34 wherein the monitoring act includes the act of monitoring a battery voltage.



36. The method as set forth in Claim 34 and further comprising the act of controlling a charging function based on one of a nominal voltage and a nominal voltage range of the one of the first battery and the second battery.

5 37. The method as set forth in Claim 36 wherein the controlling act includes controlling one of the act of terminating charging of one of the first battery and the second battery and the act of terminating a charging mode of charging of one of the first battery and the second battery.

10 38. The method as set forth in Claim 36 wherein the controlling act includes controlling one of the act of initiating charging of one of the first battery and the second battery and the act of initiating a charging mode of charging of one of the first battery and the second battery.

15 39. The method as set forth in Claim 36 and further comprising the act of selecting a battery characteristic threshold for the charging function based on one of a nominal voltage and a nominal voltage range of the one of the first battery and the second battery.

20 40. The method as set forth in Claim 39 and further comprising the act of selecting a first battery characteristic threshold for the charging function based on one of the first nominal voltage and the first nominal voltage range of the first battery.

25 41. The method as set forth in Claim 40 and further comprising the act of selecting a second battery characteristic threshold for the charging function based on one of the second nominal voltage and the second nominal voltage range of the second battery, the second battery characteristic threshold being different than the first battery characteristic threshold.

42. A battery having a Lithium-based chemistry, the battery having a nominal voltage in a nominal voltage range, the battery comprising:

a chemistry identification component indicative of the chemistry of the battery; and

5 an identification component indicative of one of the nominal voltage and the nominal voltage range of the battery;

wherein the battery is operable with an electrical device, power being transferable between the battery and the electrical device, the chemistry of the battery and the one of the nominal voltage and the nominal voltage range of the battery being

10 identifiable by the electrical device.

43. The battery as set forth in Claim 42 wherein the battery includes a controller, the chemistry identification component including the controller.

15 44. The battery as set forth in Claim 42 wherein the battery includes a controller, the identification component including the controller.

45. The battery as set forth in Claim 42 wherein the electrical device includes a battery charger operable to supply a charging current to the battery to charge the battery,  
20 the chemistry of the battery and the one of the nominal voltage and the nominal voltage range of the battery being identifiable by the battery charger.

46. An electrical combination comprising:  
a battery charger operable to supply a charging current to a battery to charge the battery; and  
a battery including a switch having an interrupt condition, in which the  
5 switch is operable to interrupt a discharge current from the battery, the battery being electrically connectable to the battery charger, the supply of the charging current from the battery charger to the battery being enabled when the switch is in the interrupt condition.

47. The electrical combination as set forth in Claim 46 wherein the switch  
10 includes a FET, the FET having an interrupt condition, in which the FET is operable to interrupt a discharge current from the battery, the FET including a body diode, the supply of the charging current from the battery charger to the battery being enabled through the body diode when the FET is in the interrupt condition.

15 48. The electrical combination as set forth in Claim 47 wherein the battery includes a controller operable to control the switch.

49. The electrical combination as set forth in Claim 48 wherein the controller is  
operable to control the switch between the interrupt condition and a second condition, in  
20 which a current is suppliable through the switch.

50. The electrical combination as set forth in Claim 49 wherein the battery  
includes a cell operable to supply a voltage to the controller, and wherein the controller  
has an operating voltage threshold, the controller being operable when the cell supplies a  
25 voltage to the controller one of equal to and greater than the operating voltage threshold.

51. The electrical combination as set forth in Claim 50 wherein the controller is  
operable to change the switch from the interrupt condition to the second condition when  
the battery is electrically connected to the battery charger and when a voltage one of equal  
30 to and greater than the operating voltage threshold is supplied to the controller.

52. The electrical combination as set forth in Claim 51 wherein, in the second  
condition, charging current is suppliable through the switch to the cell to charge the cell.

53. The electrical combination as set forth in Claim 51 wherein, when the battery is electrically connected to the battery charger and when a voltage less than the operating voltage threshold is supplied to the controller, the controller is not operable to change the switch from the interrupt condition to the second condition.

5

54. The electrical combination as set forth in Claim 53 wherein the supply of the charging current from the battery charger to the battery when the switch is in the interrupt condition increases the voltage supplied to the controller to one of equal to and greater than the operating voltage threshold.

10

55. The electrical combination as set forth in Claim 54 wherein, thereafter, the controller is operable to change the switch from the interrupt condition to the second condition.

15

56. The electrical combination as set forth in Claim 55 wherein, thereafter, in the second condition, charging current is suppliable through the switch to the cell to charge the cell.

57. A method of operating an electrical combination, the electrical combination including a battery charger operable to supply a charging current to a battery, and a battery including a switch having an interrupt condition, in which the switch is operable to interrupt a discharge current from the battery, the battery being electrically connectable to the battery charger, said method comprising the act of enabling the supply of the charging current from the battery charger to the battery when the switch is in the interrupt condition.

58. The method as set forth in Claim 57 wherein the switch includes a FET, the FET having an interrupt condition, in which the FET is operable to interrupt a discharge current from the battery, the FET including a body diode, and wherein said method further comprises the act of enabling the supply of the charging current from the battery charger to the battery through the body diode when the FET is in the interrupt condition.

59. The method as set forth in Claim 57 and further comprising the act of controlling the switch between the interrupt condition and a second condition, in which a current is suppliable through the switch.

60. The method as set forth in Claim 57 wherein the battery includes a cell operable to supply a voltage to the controller and a controller having an operating voltage threshold, and wherein said method further comprises the act of operating the controller when a voltage one of equal to and greater than the operating voltage threshold is supplied to the controller.

61. The method as set forth in Claim 60 and further comprising the act of, with the controller, changing the switch from the interrupt condition to a second condition, in which a current is suppliable through the switch, when the battery is electrically connected to the battery charger and when a voltage one of equal to and greater than the operating voltage threshold is supplied to the controller.

62. The method as set forth in Claim 61 and further comprising, when the switch is in the second condition, the act of supplying charging current through the switch to the cell to charge the cell.

63. The method as set forth in Claim 60 wherein, when the battery is electrically connected to the battery charger and when a voltage less than the operating voltage threshold is supplied to the controller, the controller is not operable to change the switch from the interrupt condition to the second condition, and wherein said method  
5 further comprises the act of increasing the voltage supplied by the cell to the controller to one of equal to and greater than the operating voltage threshold.

64. The method as set forth in Claim 63 and further comprising, after the increasing act, the act of, with the controller, changing the switch from the interrupt  
10 condition to the second condition.

65. The method as set forth in Claim 64 and further comprising, after the changing act, the act of supplying charging current through the switch to the cell to charge the cell.

15

66. A battery comprising:

a cell operable to supply a discharge current; and

a switch having an interrupt condition, in which the switch is operable to interrupt the discharge current from the cell, and a second condition, in which the current is suppliable through the switch;

wherein the battery is electrically connectable to a battery charger, the supply of the charging current from the battery charger to the cell being enabled when the switch is in the interrupt condition, charging current being suppliable through the switch when the switch is in the second condition.

10

67. The battery as set forth in Claim 66 wherein the switch includes a FET, the FET having an interrupt condition, in which the FET is operable to interrupt a discharge current from the battery, and a second condition, in which current is suppliable through the FET, the FET including a body diode, the supply of the charging current from the battery charger to the cell being enabled through the body diode when the FET is in the interrupt condition, charging current being suppliable through the FET when the FET is in the second condition.

15

68. An electrical combination comprising:  
a first battery having a Lithium-based chemistry;  
a second battery having one of a Nickel-Cadmium and a Nickel-Metal-Hydride chemistry; and  
5 a battery charger operable to charge the first battery and the second battery.

69. The electrical combination as set forth in Claim 68 and further comprising a third battery having the other of a Nickel-Cadmium and a Nickel-Metal-Hydride chemistry, and wherein the battery charger is operable to charge the third battery.  
10

70. The electrical combination as set forth in Claim 68 wherein the battery charger is operable to identify the Lithium-based chemistry of the first battery.

71. The electrical combination as set forth in Claim 70 wherein the first battery  
15 includes an identification component indicative of the Lithium-based chemistry of the first battery, and wherein the battery charger receives a signal indicative of the Lithium-based chemistry of the first battery.

72. The electrical combination as set forth in Claim 70 wherein the battery  
20 charger includes a controller operable to identify the Lithium-based chemistry of the first battery.

73. The electrical combination as set forth in Claim 68 wherein the battery charger includes a charging circuit connectable to a power source and operable to supply a  
25 charging current to the first battery and to the second battery.

74. The electrical combination as set forth in Claim 73 wherein the battery charger includes a controller operable to control the charging circuit and to control the charging current supplied through the charging circuit to the first battery and to the second  
30 battery.



75. The electrical combination as set forth in Claim 74 wherein the controller is operable to identify the Lithium-based chemistry of the first battery and to control the charging circuit to control charging current supplied through the charging circuit to the first battery.

5

76. The electrical combination as set forth in Claim 74 wherein the controller is operable to control the charging circuit to supply charging current by a first charging algorithm to the first battery and by a second charging algorithm to the second battery, the first charging algorithm being different than the second charging algorithm.

10

77. The electrical combination as set forth in Claim 68 wherein the first battery has a first nominal voltage in a first nominal voltage range, wherein said electrical combination further comprises a third battery having a nominal voltage in a nominal voltage range, the nominal voltage of the third battery being different than the first nominal voltage, the nominal voltage range of the third battery being different than the first nominal voltage range, and wherein the battery charger is operable to charge the third battery.

15

78. The electrical combination as set forth in Claim 77 wherein the battery charger is operable to identify one of a nominal voltage and a nominal voltage range of the first battery and of the third battery.

20

79. A battery charger:  
at least one terminal to electrically connect to a lithium-based chemistry  
battery pack, the battery pack having a nominal voltage; and  
a controller operable to provide a charging current to the battery pack  
5 through the at least one terminal, the controller operable to select a threshold for a  
charging function according to a nominal voltage of the battery pack.

80. The battery charger as set forth in Claim 79 wherein the nominal voltage of  
the battery pack is included in the voltage range of approximately 9.6 –V to approximately  
10 30-V.

81. The battery charger as set forth in Claim 79 wherein the controller includes  
a first charging module and a second charging module, the first charging module operable  
to provide a first charging current to the battery pack and the second charging module  
15 operable to provide a second charging current to the battery pack.

82. The battery charger as set forth in Claim 81 wherein the first charging  
current and the second charging current differ in one of average current amplitude and  
duty-cycle.

20

83. The battery charger as set forth in Claim 82 wherein the first charging  
module includes a fast charge module.

84. The battery charger as set forth in Claim 83 wherein the first charging  
25 current includes a fast charge current.

85. The battery charger as set forth in Claim 81 wherein the controller further  
includes a third charging module and a fourth charging module, the third charging module  
operable to provide a third charging current to the battery pack and the fourth charging  
30 module operable to provide a fourth charging current.

86. The battery charger as set forth in Claim 85 wherein the first charging module is a fast charging module, the second charging module is a step charging module, the third charging module is a trickle charging module, and the fourth charging module is a maintenance charging module.

5

87. The battery charger as set forth in Claim 86 wherein the first charging current is a fast charge current, the second charging current is a step charge current, the third charging current is a trickle charge current, and the fourth charging current is a maintenance charge current.

10

88. The battery charger as set forth in Claim 81 wherein the controller includes a charging algorithm.

89. The battery charger as set forth in Claim 88 wherein the controller implements the charging algorithm in the first charging module and in the second charging module.

15

90. The battery charger as set forth in Claim 89 wherein the controller implements the charging algorithm in a first manner in the first charging module and in a different second manner in the second charging module.

20

91. The battery charger as set forth in Claim 89 wherein the controller further includes a third charging module and a fourth charging module, the third charging module operable to provide a third charging current to the battery pack and the fourth charging module operable to provide a fourth charging current, the controller implementing the charging algorithm in the third charging module and in the fourth charging module.

25

92. The battery charger as set forth in Claim 91 wherein the first charging module is a fast charging module, the second charging module is a step charging module, the third charging module is a trickle charging module, and the fourth charging module is a maintenance charging module.

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46



INVESTOR IN PEOPLE

Application No: GB 0327218.4  
Claims searched: 1 and 29

Examiner: Peter Keefe  
Date of search: 15 April 2004

## Patents Act 1977 : Search Report under Section 17

### Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	1-41	US 5986430 A	MOTOROLA column 2 lines 22-58; claim 1
X	1-41	US 5684387 A	MOTOROLA column 1 lines 9-27; column 2 lines 29-44; column 3 lines 7-36
X	1, 29 at least	US 5691623 A	TSANTILIS column 1 lines 19-34; column 2 lines 38-44
X	1, 29 at least	US 5280229 A	BSG SCHALTTECHNIK column 3 lines 3-11; column 4 lines 63-68
X	1, 29 at least	US 5355073 A	COMPAQ column 1 line 50-column 2 line 38
X	1, 29 at least	EP 0419806 A2	MAKITA column 2 line 31-column 3 line 21
X	1, 29 at least	DE 19617805 A	MAKITA see abstract
X	1, 29 at least	DE 3637669 A	BOSCH see abstract

### Categories:

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art.
Y Document indicating lack of inventive step if combined with one or more other documents of same category.	P Document published on or after the declared priority date but before the filing date of this invention.
& Member of the same patent family	E Patent document published on or after, but with priority date earlier than, the filing date of this application.

### Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>w</sup>:

H2H

Worldwide search of patent documents classified in the following areas of the IPC<sup>7</sup>:

H02J



47



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The following online and other databases have been used in the preparation of this search report:

WPI, PAJ, EPODOC

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